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SSTOP* User's Guide

* Offline Signal System Optimization Program

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PREFACE

This user's guide incorporates the most recent revisions to the SSTOP program, which was originally developed in the late 1970's. That original development effort was directed toward providing traffic engineers with an analytic tool by which fixed-time/time-of-day signal control plans could be generated offline with relative ease and minimal expense. Program SSTOP was prepared under the direction of the TRAFFIC RESEARCH GROUP at McMaster University through contract with the Urban Transportation Research Branch of Transport Canada during the period September 1977 - May 1979. The initial documentation describing the results of that extensive research effort comprised two volumes: VOLUME 1 - PROJECT SUMMARY included a review of study objectives, work tasks undertaken, a summary of results achieved, commentary on application validity, and recommendations for future improvements; VOLUME 2 - USER'S GUIDE was a comprehensive document which introduced the basic conceptual notions incorporated in the SSTOP program, and provided extensive guidance for proper and effective use of the package. The current guide replaces Volume 2, incorporating the latest revisions, while retaining the basic format of presentation.

Prior to outlining the nature and scope of the most recent improvement, it would perhaps be useful to review the context within which the program was developed. During all stages of SSTOP development, every effort was made to ensure that the resultant package would be truly useful to traffic engineers. For this purpose, a C.I.T.E. Advisory Committee composed of practicing traffic engineers from across Canada was established to make recommendations concerning the format and operation of the program. In this rather unique manner, SSTOP was developed to successfully serve the real needs of practitioners.

Furthermore, in early 1979, Transport Canada funded three field demonstration projects to examine the effectiveness and validity of SSTOP. The demonstration projects were conducted by consulting engineering firms and were directed toward applying SSTOP to existing signalized urban networks, obtaining timing plans, and examining the effectiveness of those plans. In addition, each firm commented on the usefulness of the SSTOP package with regard to ease of use, effectiveness of the user's guide, and overall application efficiency.

The results of those studies were documented in two reports; the DeLuc/DeLCan applications in Quebec City and Montreal were presented in a report entitled Traffic Optimization Demonstration Projects - Montreal-Quebec; the I.B.I. Group application in Cambridge was presented in a report entitled SSTOP Demonstration Program for the City of Cambridge. Although each consultant experienced some problems, the groups felt that SSTOP had great potential for application and wide use by traffic engineers, and the improvements effected in SSTOP since those investigations should guarantee full attainment of that potential.

Further testing and evaluation of the SSTOP program was undertaken by the IBI Group in 1980. This work was funded and monitored by the Ontario Ministry of Transportation and Communications and the study network selected was the downtown area of Galt in the City of Cambridge, Ontario.(5)

In a manner similar to that undertaken in the earlier evaluation tests of SSTOP, the internationally recognized TRANSYT optimization program was run in parallel with the SSTOP program. The TRANSYT/7 program coding requirements and the optimized settings generated therefrom were considered to be the standards against which corresponding elements of the SSTOP program would be compared. The results indicate that the signal timings generated by SSTOP compare favorably with those generated by TRANSYT. Input preparation for SSTOP is easier and faster than for TRANSYT. Computer requirements and running costs are much lower for SSTOP.

Since completion of the above studies, the Ontario Ministry of Transportation and Communications provided continuing funds and staff support to further validate and improve SSTOP. Also, the SSTOP program has been successfully applied and the results implemented in several cities.

The most extensive application of SSTOP was done by DeLCan for the Region of Waterloo. During this study, the program was thoroughly tested and improved and the original User's Guide expanded.

As a result of all these studies and by utilizing comments from program users, various programming modifications arose from the desire to improve program logic for special cases. These modifications were: to decrease program storage requirements, include time-space diagrams, and to effect use of the program as an evaluator (of both fuel consumption and delay) of specified signal control plans. Several of these changes did affect contents of the user's guide. For this reason, a new SSTOP program and User's Guide have been made available and all versions of both program and guide obtained prior to January 1983 are to be considered out-of-date; for best results, obtain copies of the latest version.

ACKNOWLEDGEMENTS

Many individuals and organizations made significant contributions to the development of the original SSTOP program and their active participation and support were acknowledged in the original User's Guide (May 1979).

Further testing, development and improvements of SSTOP were done by DeLCan Ltd., McMaster University, Ontario Ministry of Transportation and Communications (MTC), and IBI Group Ltd.

Mr. Joseph Lam and Mr. Peter deGroot were the major contributors from DeLCan who tested the program thoroughly and made numerous significant program improvements. The McMaster University efforts were coordinated by Brian L. Allen and Erhart C. Schroeder. Mr. Alexander Ugge of MTC monitored and coordinated the SSTOP development, adapted the program to IBM computer systems and, along with Mr. John McGill and Mr. Stephen Erwin, made various program improvements. Mr. Scott McMillan of M.M. Dillon Ltd. conducted detailed SSTOP vs TRANSYT comparisons.

Several SSTOP users (e.g. Read Voorhees Associates) also helped to detect minor deficiencies and suggested SSTOP improvements.

This new User's Guide was prepared by Brian L. Allen, Alexander Ugge, and John McGill. Excerpts from the DeLCan SSTOP Manual (written by Joseph Lam and Peter deGroot) are included in this Guide; in particular, Appendix D was prepared in its entirety by those individuals.

Included in this latest version of the User's Guide is the "Metropolitan Toronto Intersection Capacity Guide" which was provided by Metropolitan Toronto Roads & Traffic. This report may be found in it's entirety in Appendix B. The material contained in this report was prepared by the staff of the Traffic Control Centre, Traffic Branch, Metropolitan Toronto Roads and Traffic Department under the guidance of Mr. David Richardson.

DISCLAIMER

Although this program has been subjected to many rigorous tests - no warranty, expressed or implied, is made by the Ministry of Transportation and Communications as to the accuracy and functioning of the program, nor shall the fact of distribution constitute any such warranty, and no responsibility is assumed by the Ministry in any connection therewith.

CAUTION

User's of the previous version of SSTOP should be advised that due to program logic refinements, the output from the new version of SSTOP cannot be compared to output from the previous version of SSTOP. Data sets which were run on the previous version of SSTOP should be rerun to establish new performance indicies and system MOE's. Data sets used previously will run using the new version of SSTOP without necessary revisions.

CONTENTS

PREFACE		i
ACKNOWLEDGEMENTS		iii
DISCLAIMER		iv
CONTENT		v
LIST OF FIGURES		viii
LIST OF TABLES		ix
GLOSSARY OF SELECTED TERMS		x
CHAPTER 1	INTRODUCTION	1
CHAPTER 2	THE PROGRAM SSTOP	3
2.1	Input-Output Outline	3
2.2	Program Operation and Theory	4
2.3	Time Requirements	9
2.4	Program Specifications	9
CHAPTER 3	INPUT REQUIREMENTS	10
3.1	Card Type 1 - Title Card	11
3.2	Card Type 2 - Network Parameters Card	11
3.3	Network Coding	13
3.4	Sequencing of Card Types 3 and 4	19
3.5	Flow Specification and Units	20
3.6	Card Type 3 - Link Information Card	23
3.7	Card Type 4 - Approach Card	25
3.8	Card Type 5 - Optional User Parameters	28
3.9	Card Type 7 - Economic Analysis	30
3.10	Card 99999 - End of Data Card	37
3.11	Card Type 6 - Evaluator Card	38
3.12	Card Type 88888 - End of Data	41
3.13	Card Type 10 - Time Space Diagrams Parameters	41
3.14	Card Type 11 - Time Space Diagrams Link Card	42
3.15	Summary of Input Data Requirements and Data Deck Structure	43
CHAPTER 4	OUTPUT	49
4.1	Output Description	49
4.2	Output Interpretation	68
REFERENCES		72

Appendix A SAMPLES NETWORK (ST. CATHARINES) 74
A.1 Card Types 1 and 2 79
A.2 Series 100 Intersections 79
A.3 Series 200 Intersections 83
A.4 Series 300 Intersections 83
A.5 Series 400 Intersections 92
A.6 Series 500 Intersections 92
A.7 Series 600 Intersections 95

Appendix B SPECIAL PARAMETERS 117
B.1 Saturation Flow 117
B.1.1 British Method 117
B.1.2 Australian Method 119
B.1.3 Field Measurement of Saturation Flow 120
B.1.4 Toronto Method 126
B.2 Design Speed 157
B.3 Platoon Dispersion Factor 159
B.3.1 Robertson's Platoon Dispersion Model 161
B.3.2 Model Calibration 161
B.3.3 Feasibility of Coordination 162

Appendix C DETAILED DESCRIPTION OF SSTOP ALGORITHM 163
C.1 Introduction 163
C.2 Signal Timing Computation for Individual Traffic Signals 163
C.2.1 Volume-Saturation Flow Computations 163
C.2.1.1 Simple Two-Phase Signal 163
C.2.1.2 Split Phase Signal 164
C.2.2 Cycle Length Computations 166
C.2.2.1 Absolute minimum cycle length 166
C.2.2.2 Webster's cycle calculations 167
C.2.2.3 Minimum green cycle lengths 168
C.2.2.4 Final cycle length candidates 169
C.3 System Signal Timing Computations 170
C.3.1 Signal Timing Design for Isolated Control 171
C.3.2 Computation of Delay/Difference-of-Offsets Relationships 174
C.3.3 Generation of Link Entry Patterns 174
C.3.4 Downstream Arrival Computation 176
C.3.5 Performance/Difference-of-Offset Relationships 179
C.3.6 Measure of Link Importance 181
C.3.7 Link Ranking Process 186
C.3.8 Offset Optimization Algorithm 186
C.3.9 System Performance Evaluation 191

Appendix D CODING FOR SPECIAL FEATURES AND SAMPLE WORK NETWORK OUTPUT (WATERLOO) 193
D.1 Coding for Special Features 194
D.1.1 Traffic Characteristics 194
D.1.2 Geometrics 195
D.1.2.1 Exclusive Left Turn Lane 195

D.1.2.2 Exclusive Right Turn Lane 196
D.1.2.3 Right Turn Island 196
D.1.2.4 'T' Intersections 197
D.1.2.5 Dual Left Turn Lanes 197
D.1.2.6 One Way Streets 197
D.1.3 Signal Timing 198
D.1.3.1 Advanced Green 198
D.1.3.2 Extended Green 198
D.1.3.3 Simultaneous Left Turns 198
D.1.3.4 Traffic Actuated Control 199
D.1.4 Output Evaluations 199
D.1.4.1 Cycle Length 199
D.1.4.2 Offset 200
D.1.4.3 Phase Duration 201
D.2 Sample Network (Waterloo) 201
D.2.1 Network Coding 203
D.2.2 Output Interpretation 203

Appendix E ERRORS 225
E.1 Fatal Error Messages 226
E.1.1 Error 1 226
E.1.2 Error 2 226
E.1.3 Error 3 227
E.1.4 Error 4 227
E.1.5 Error 5 227
E.1.6 Error 6 227
E.1.7 Error 7 228
E.1.8 Error 8 228
E.1.9 Error 9 228
E.1.10 Error 10 229
E.1.11 Error 11 229
E.1.12 Error 12 229
E.1.13 Error 13 229
E.1.14 Error 14 230
E.1.15 Error 15 230
E.1.16 Error 16 230
E.1.17 Error 17 231
E.1.18 Error 18 231
E.1.19 Error 19 231
E.1.20 Error 20 231
E.1.21 Error due to Oversaturation 232
E.2 Illegal Data Check 233
E.3 Non-Fatal Messages 234

Appendix F COMPUTER SYSTEM SET-UPS 236
F.1 IBM Control (JCL) 237
F.2 CDC Control 237

LIST OF FIGURES

Figure 3.1	Network Coding	14
Figure 3.2	Priority Green Coding Example	16
Figure 3.3	Source Link Coding Example	18
Figure 3.4	Card Types 3 and 4 Sequencing	21
Figure 3.5	Link Departure Pattern	33
Figure 3.6	Additional Fuel Consumption Due to Speed Changes	35
Figure 3.7	Card Type 6 - Evaluator Card	39
Figure 3.8	Summary of Data Input Requirement for Optimization	44
Figure 3.9	Data Deck Structure	48
Figure 4.1	Typical Output - Card Types 2 and 5	50
Figure 4.2	Typical Output - Phase Information	52
Figure 4.3	Typical Output - Link Characteristics	53
Figure 4.4	Typical Output - Traffic Characteristics	56
Figure 4.5	Typical Output - Evaluator Input Data	57
Figure 4.6	Cycle Length Calculations	58
Figure 4.7	Link Performance Indicators	60
Figure 4.8	Calculated Signal Timings	62
Figure 4.9	Total System Performance Values	65
Figure 4.10	Signal Timing for Series 600 Intersections	69
Figure A.1	St. Catharines Location	75
Figure A.2	St. Catherines Network	76
Figure A.3	St. Catherines Network - Schematic Representation	77
Figure A.4	Card Types 1 and 2 Coding	78
Figure A.5	Series 100 Intersection Data	81
Figure A.6	Series 100 Intersection Coding	82
Figure A.7	Series 200 Intersection Data	84
Figure A.8	Series 300 Intersection Coding	85
Figure A.9	Series 300 Intersection Data	86
Figure A.10	Series 300 Intersection Coding	87
Figure A.11	Series 400 Intersection Data	88
Figure A.12	Series 400 Intersection Coding	89
Figure A.13	Series 500 Intersection Data	90
Figure A.14	Series 500 Intersection Coding	91
Figure A.15	Series 600 Intersection Data	93
Figure A.16	Series 600 Intersection Coding	94
Figure A.17	Output for 80 Second Cycle	96
Figure B.1	Saturation Flow Summary	125
Figure B.2	Relationship Between Smoothing Factor and Travel Time	160
Figure C.1	Entry Flow on a Typical Link	173
Figure C.2	Total Link Entry Flow Pattern	175
Figure C.3	Traffic Transition Process at a Typical Link's Exit Signal	178
Figure C.4	Delay-Offset and Stop-Offset Curves	183

Figure C.5 Performance Index - Offset Curve 184
Figure C.6 Performance Index - Difference-of-Offset Curve for a Typical Link 185
Figure C.7 Quadratic Approximation of a Link Performance Function 188

Figure D.1.1 Small Network in Waterloo 194
Figure D.1.2 Performance Index and Cycle Length Curve 200
Figure D.2.1 Waterloo CBD Network - Signalized Intersection 202

Figure E.1 Illegal Data Entries 235

LIST OF TABLES

Table 3.1 Geometric Features Summary 45
Table 3.2 Data Card Requirements and Structure 46

Table B.1 Manpower Requirements for Saturation Flow Studies 121
Table B.2 Sample Saturation Flow Data Field Sheet 122

GLOSSARY OF SELECTED TERMS

'A' Format - alphanumeric characters, including letters and numerals, are allowed as input.

Approach - that portion of an intersection leg which is used by traffic approaching the intersection. An approach may be represented by one or more links.

Average Speed - the speed over a specified section of roadway that is the distance travelled divided by the travel time. Normally referred as a overall travel speed which is the summation of travel distances divided by the summation of overall travel times.

Clearance Interval - the display time of the signal indication(s) allocated for vehicles to clear the intersection after the green interval. It is comprised of amber and/or all red indications. In special cases such as priority green phases, it may also be a solid green indication during which time opposing traffic does not proceed.

Cycle Length or Cycle - the total time required for one complete sequence of phases to occur.

Degree of Saturation - the link flow to saturation flow ratio divided by the green time to cycle length ratio.

Design Speed - The speed of travel which a vehicle could maintain between two successive stop lines on a specified arterial assuming no delays were occasioned as a result of signal timing (no stops or queueing at the stopline). Implicitly it does include the effects of such factors as intensity of adjacent land use, parking, mid-block pedestrian cross-walks, bus stops, and traffic composition. (See Section B.2).

Delay - the time lost while traffic is impeded by some element over which the driver has no control. For purposes of this report, it is the time lost at a signalized intersection which is operating under a fixed-time control mode.

Direction Code - the last digit of the link number.

Effective Green - the time period during the green and clearance intervals in which the flow rate may be assumed to be equal to the saturation flow rate given sufficient demand. In general, it is assumed that the duration of effective green may be approximated by the duration of actual green.

External link - a section of roadway over which vehicles flow into the network under consideration. An external link has no upstream intersection.

'F' Format - real numbers only are allowed as input.

'I' Format - integer values only are permitted as input. Decimal points are not permitted. A negative or plus sign may be included for link numbers.

Ideal Offset - the offset which will result in the minimum combined value of delay and stops for a given link.

Importance Factor - a relative measure of a link's importance within the network. Practically, it is analogous to the sensitivity of that link's performance towards the choice of offset (See Section C.3.6).

Interval - an exclusive division within a cycle in which the signal indication does not change.

KIKOUT - the subroutine in SSTOP which identifies those signals incapable of operating at the system trial cycle length, due to capacity and/or minimum green constraints. No offset optimization for links flowing into or emanating from these signals is performed. Additionally, signals isolated from the network due to the above process are also excluded since offset optimization can no longer be performed (See Section C.3.1).

Link - a representation of a one-directional segment of roadway, which for internal links connects two intersections, or for external links, terminates at an intersection.

Lost Time - the time period during the green and/or clearance intervals which is not utilized for the discharge of vehicles. It is equal to the length of green, amber and all-red intervals minus the sum of the effective greens. Normally, it is sufficient to assume that the lost time is equivalent to the clearance time.

Minimum Green - the minimum required green time to satisfy local intersection restraints. Usually, it is equal to the minimum required pedestrian walk time on the longest crosswalk parallel to the approach under consideration.

Negative Link - a link number proceeded by a negative sign indicating the existence of an advanced green indication for left-turning traffic.

Neutral Link - a link number devoid of any leading signs.

Offset - the number of seconds or the percent of the cycle length that the green signal indication appears at a given signal with respect to a certain instant used as a time reference base. Generally, it is used to indicate the time difference between the start of the green intervals which control traffic flow in the same direction at two successive intersections.

Offset Number - in SSTOP it is the number of seconds or percent of the cycle length from the commencement of the first green indication of the first phase at an intersection, with respect to the start of the first green of the first phase of the last intersection in the output of SSTOP.

Phase - the sequence of one or more intervals displayed to one or more streams of traffic which, during the cycle, receive simultaneous right-of-way.

Platoon Dispersion Factor - The product of the parameters α and β in Robertson's platoon dispersion model. (See Sections B.3 and C.3.4.)

Positive Link - a link number proceeded by a plus sign indicating the existence of a delayed green indication for left-turning vehicles.

Priority Green - the green interval of a split phase which allows a left-turn right-of-way movement. It can be either an advanced or delayed green indication.

Random Delay - the component of delay at an intersection which results from random flow variations at that intersection.

Saturation Flow - the maximum rate of flow at which an intersection approach can discharge vehicles. For purposes of SSTOP, it is usually expressed in through car units (TCU) per hour of green. (See Section 3.5 and B.1.)

Split Phase - a phase which is comprised of two green intervals, one of which, in SSTOP, is assumed to be a priority left-turn indication for one approach.

SSTOP - Signal System Optimization Package - used generally to describe the entire package including the optimization program and the User's Guide. Often used more specifically to refer to the optimization program itself.

Stop Penalty - a measurement of the importance of a stop within the network. It is used to convert a stop to equivalent units of delay time.

Travel Time - in SSTOP output it represents the total link or network travel time, including stops and delays, or all vehicles on the link or network, during a one-hour time period.

Uniform Delay - that portion of the delay at an intersection which is a function of the offset and cycle length.

1. INTRODUCTION

Maintaining a high level of service for urban transportation systems has become increasingly difficult for transportation agencies in this era of financial restraint. The emphasis, apart from upgrading the quantity and quality of public transportation systems, has shifted to optimizing traffic movement on existing street networks rather than the continuance of costly construction programs associated with providing additional urban arterials and freeways. In this context, urban traffic signal systems have a significant influence on the presence or absence of traffic congestion in cities. Suboptimal signal settings and the lack of necessary methods to easily upgrade these settings tend to compound existing congestion problems and hamper the traffic engineers in their attempts to effect more efficient travel.

In an attempt to assist traffic engineers in developing efficient signal plans, several computerized algorithms producing optimal signal settings have been developed over the past several years. A few of them, in fact, have been shown to produce very acceptable settings which can significantly improve upon the efficiency of traffic movement in urban street networks. Unfortunately, however, these analytic tools are not being used by the majority of traffic engineers for whom they were developed. It would appear that the major reasons for this reluctance lie with such concerns as data requirements, ease of use and understanding of output, users' guide terminology and comprehensiveness, and computer requirements and running costs. Regardless of the precise nature of these many concerns, there is a definite need to make available an easily used and efficient package.

This document is intended to guide traffic engineering practitioners in the use of a computerized signal timing algorithm which is easily understood, easy to apply, efficient, and ultimately, capable of developing optimal signal settings offline for implementation by traffic engineers especially in small to medium sized cities. This is achieved through presentation of a well-tested offline optimization program with the necessary information required for proper comprehension, operation and application of the program.

The Signal System Optimization Program (SSTOP), was originally developed as an online traffic signal optimization program during the final stage of the Improved Operation of Urban Transportation Systems (IOUTS) study conducted by the Metropolitan Toronto Roads and Traffic Department under contract to the Transportation Development Agency and the Ontario Ministry of Transportation and Communications. This real-time program has been rewritten as an offline analysis tool for establishing optimal settings for fixed-time/time-of-day signal

systems.

Since fullest utilization of SSTOP will be achieved only if the theory and operation of the program are adequately understood, this guide includes numerous details which are not normally associated with a user's guide. The program is introduced in Chapter 2 by providing an overview of the input and output, program theory, features, limitations and time requirements. The input and output of the program are dealt with explicitly in Chapters 3 and 4 respectively. To facilitate input data coding for multi-time users, the input requirements have been summarized at the end of Chapter 3.

A fully worked network example for St. Catherines, Ontario is presented in Appendix A. Important input parameters which may not be commonly understood or uniformly applied are discussed in greater detail in Appendix B. A detailed description of the theoretical basis for SSTOP is contained in Appendix C. Appendix D contains coding for special features & a sample network output, from the Region of Waterloo study, prepared by DeLCan, to further aid users in the preparation & interpretation of typical network timing analysis. SSTOP, during the reading of input data, performs limited data checks. These checks ensure that the integrity of the network is maintained and also that certain program constraints are not violated. Program identified errors will result in a printed error message and, in most cases, termination. These error messages are described in Appendix E. An option is also available which will perform a detailed check of input data to ensure that only legitimate entries are made. This option is described in Chapter 3 and Appendix E.

A listing of SSTOP is not included in this document. Users wishing to obtain a listing of the program may write to the address listed in the preface.

2. THE PROGRAM SSTOP

During the IOUTS research and development study, four existing offline signal system optimization algorithms were evaluated in depth. Based upon experience gained from this evaluation, as well as a review of existing signal timing strategies, a Real-Time Optimization Program (RTOP) for traffic signal networks was written and tested on-street {1,2,3}. The RTOP program was constructed in modular form, by extracting what were considered to be the best signal timing components from the available packages, and restructuring them to produce an effective real-time program for computerized traffic signal networks.

The research effort undertaken by the Traffic Research Group at McMaster University is an extension of the IOUTS work. In addition to the changes necessary for conversion of the real-time program to an offline version, the input and output sections were rewritten to meet the particular requirements of this study. Furthermore, several major additions have been made to the basic framework of the real-time program which add to the versatility and flexibility of the offline optimization program SSTOP.

The following sections of this chapter include a very brief overview of the program and are intended to provide the user with a basic understanding of SSTOP operation prior to dealing explicitly with the input and output requirements associated with an actual application.

2.1 INPUT-OUTPUT OUTLINE (see also Chapters 3 and 4)

Data input requirements for SSTOP have been limited to those items which are normally required for manual generation of a signal timing plan or which can be otherwise easily obtained. Transfer of data to SSTOP is made through the use of four card types, with a fifth type being optional. One type 1 card provides a run title to the program, while the one type 2 card specifies a variety of network or global parameters. Card types 3 and 4 supply SSTOP with the detailed signal, traffic and geometric characteristics of the network which are required for the optimization process. Although default values for several parameters have been included in the program, an optional card type 5 may be used to alter those values if desired and an optional card type 7 may also be included if an economic analysis is required. End of data is signified by placing a card with 9's punched in the first five columns at the end of the data deck. Further discussion of each card type is contained in Chapter 3. An additional card type 6 is required for each intersection if the program is to be used for evaluation purposes and if time-space diagrams are desired there must

be one card type 10 & at least one card type 11 for each diagram to be output.

The output is structured so that users may easily inspect input parameters and evaluate resulting signal settings. Various link and system performance values including degree of saturation, uniform and random delay and travel time are provided to facilitate this evaluation process. The network signal settings are presented in a format which facilitates easy field implementation. Chapter 4 contains a detailed explanation of the output.

2.2 PROGRAM OPERATION AND THEORY (see also Appendix C)

The first operation of SSTOP is to read in, check, and sort the input data. Checks in the following areas are made:

a) input data cards occur in the proper sequence?

b) the correct number of each card type has been supplied?

c) the size of the network does not exceed program capabilities?

d) correct number of links and intersections specified on the card types?

Violation of any of these consistency checks will result in printing of a diagnostic message, followed by program termination. The possible messages and potential remedial actions are listed in Appendix E. Several non-fatal messages may also be printed, but these should prove self-explanatory.

An optional data check which is particularly useful for data card decks being used for the first time is also available. This option allows the user to ensure that all integer data fields on card types 3 and 4 contain only numeric or blank entries. Section 3.2 and E.2 provide a complete description of this option. Comparison testing, i.e. ensuring that specified parameter values fall within an acceptable range (e.g. volume greater than 10, less than 2000), is not performed. Although the user must ensure that all entries are within an acceptable range, such checks may be coded into the program with little effort.

Upon completion of these tasks, the data for each individual signalized intersection is considered and a number of possible cycle lengths are calculated on the basis of the following design criteria:

a) Absolute minimum cycle length: the cycle length at any signal must not be less than the aggregate minimum pedestrian walk time and clearance interval requirements for each phase.

b) Webster's cycle calculations: two cycle length values are calculated based on Webster's Method {4} to satisfy the capacity restraints. One is the minimum cycle length necessary to provide adequate capacity, and the other is the practical minimum cycle length which allows for an additional 10 percent capacity to cope more efficiently with random traffic fluctuations.

c) Minimum green cycle calculations: considering both the minimum green requirement and vehicular flows for each phase, two cycle length values are calculated. One provides the minimum green time necessary to provide adequate capacity for each phase (including constraints), and the other, the practical minimum green time necessary to provide a 10 percent reserve capacity for each phase. This set of calculations ensures that both minimum green time and capacity constraints are met for each phase.

Based upon the above computations, two final cycle lengths are identified for each individual signalized intersection; one a practical minimum, and the other, a practical optimum. Both selected cycle lengths have a minimum allowable value equal to the absolute minimum cycle length, as defined in a) above. In any case, the minimum allowable cycle length selected by the program may not be less than 40 seconds. Also, neither of the two final cycle lengths will be less than the minimum system cycle length specified on Card Type 2 (see Section 3.2). Neither of the selected cycle lengths will exceed the Maximum Kickout Length specified on Card Type 2 (see Section 3.2).

As an integral part of the above analysis, the signal splits for each of the possible cycle lengths are calculated, based on Webster's Method {4} by setting the green times proportional to their respective volume/saturation flow (V/S) ratios while simultaneously ensuring that minimum green constraints are not violated. Should any signal be oversaturated, that is, the sum of the critical V/S ratios exceed 1.0, a message is printed and the program terminated (see Section E).

Inherent in the split calculation is a unique procedure by which the operation of advanced or delayed greens are explicitly accounted for.

Briefly, SSTOP calculates the green time necessary to service the left-turning vehicles, assuming that a given number of these may be cleared during the amber period. The solid green period for the through movements and right turns is then calculated, recognizing that a number of the through and right-turning vehicles on the approach with the advanced or delayed green have also cleared during the priority green period. The user must determine which locations require a priority green prior to network coding. The program also assumes that flow on the link(s) parallel to the priority green link occurs during the clearance interval immediately following (for advanced greens) or proceeding (for delayed greens) the priority green. Section 3.3 provides details concerning priority green coding, while Section C.2.1.2 outlines SSTOP operation in priority green situations.

After the signal timing computations have been completed for each individual intersection in the network, the timing information along with the link approach volumes and their related saturation flows are stored for subsequent network analysis. For overall network control, up to ten specified candidate system cycle lengths are evaluated to identify the 'best' cycle length for the system. To reduce computing time requirements, SSTOP performs some calculations using two second increments. For this reason, odd-numbered cycle lengths should be avoided as they do not result in an integer number of steps. Generally, SSTOP tends to treat odd-numbered cycle lengths similar to

the next lower even-numbered cycle length. Although a two second increment between trial cycle lengths is possible, it is recommended that a ten second cycle length increment and an even valued minimum trial cycle length be used (e.g. minimum trial cycle length = 64 seconds), as this allows every trial cycle to be divided into an integer number of steps.

For each candidate cycle length the following general functions are then performed:

a) Intersections which will be placed under coordinated control in the system and those which will be isolated from the system are identified. Whenever the candidate system cycle length is less than the required individual minimum cycle length at an intersection, that intersection is placed under isolated control.

   This particular operation is performed by the 'KIKOUT' subroutine. If an intersection is identified as not being capable of operating effectively at the trial cycle length due to either minimum pedestrian requirements, capacity considerations or combination thereof, it is 'removed' from the network, and thus, offset optimization is not performed on that signal for that trial system cycle length. The isolated signals are allowed to operate at their optimum cycle lengths, thereby avoiding the possibility of oversaturated signals in the network. The optimum cycle length for any kicked out signal is less than or equal to the 'Maximum Kikout Cycle Length' which is required as input on Card Type 2 (see Section 3.2). If this value is too low, it is possible that a kicked out signal may be oversaturated, in which case SSTOP under-estimates delay and stop values for this signal.

   Should there be no coordinated signals remaining after this operation, a message is printed (see Section E.3). The next trial cycle is then processed with no further analysis being performed for the present trial cycle length. While performance of the isolated signals is evaluated separately from the remainder of the network, a total performance value is computed by combining the performance indices for both the isolated and coordinated signals. This allows the user to determine whether the network operates most efficiently at a lower cycle lengths, or whether the entire network should be operated at some higher value.

b) Calculation of the signal timing intervals for both the co-ordinated and the isolated signals in the network. A maximum of six green intervals per intersection is allowed. A split phase consisting of a priority green and a solid through green contains two green intervals.

c) Computation of delay/difference-of-offset relationships for the coordinated signals in the network: First, link entry flow patterns are generated using the signal and volume data from the upstream signal. Generally, a single link is sufficient to represent an approach leg in the network. In certain cases however, the single link representation is inadequate. Therefore provision is made within SSTOP to allow a given section of roadway connecting two signals to be represented by two or more links. These links are termed parallel links. (See Section 3.3 for

further explanation.) For parallel links it is assumed that the shape of the link entry flow curve is identical for both links. The magnitude of the curve for each of the links is dependent upon the ratio of their exit volumes. Thus, if link A accommodates 70 percent of the total approach volume, its link entry flow curve will be seven-thirds as great as that of link B, but, as previously indicated, it will have the same shape (see Sections C.3.3 and C.3.4).

Link exit flow patterns are then formed at the downstream signal. Allowance is made for the effect of dispersion of the traffic platoon as it travels downstream along the link, using Robertson's platoon dispersion model {5}. Finally, for every offset difference between the upstream and downstream signals, a pair of delay and stop values is computed from the arrival and departure patterns at the link exit signal, based on the logic adapted from the GLC-Combination Program {6}. The above delay value accounts only for the effect of coordination and does not allow for capacity constraints, thus rendering the value inappropriate for cycle length comparison. Therefore, to complete the delay computation, a random delay component is included which takes into account the delay caused by random fluctuations in the traffic volume. The random delay component is a function of the degree of saturation only, as described by Robertson {7}. Thus, an approach represented by two parallel links will have two random delay calculations, whereas if it was represented by a single link, it would only have one. If the degrees of saturation on the parallel links were equal, then the approach with the parallel link representation would have twice as much random delay attributed to it as the same approach with the single link representation. A parallel link representation of an approach may therefore tend to overemphasize the random delay component.

d) Identification of the ideal offset for each link: A performance index is computed for each given offset difference between the upstream and downstream signal. This performance index is based on the amount of uniform delay, the amount of random delay, and the estimated number of stops resulting from any particular offset difference. The best offset difference for the pair of signals in question is the one given by the minimum performance index.

e) Calculation of link importance factor: The importance of a link is analogous to the sensitivity of its performance towards the choice of offset difference. For a highly important link, an offset close to the ideal value should be implemented, whereas for an unimportant link the use of the ideal offset is not essential. These importance factors are derived from the performance curves as discussed in Section C.3.5. Using this importance factor the links are ranked between one and one hundred, giving an indication of the relative importance with respect to the most critical link in the system. Provision is made in the input data to allow specification of a link importance factor multiplier which is multiplied by the link importance factor before ranking. See Section 3.7, C.3.6 and C.3.7 for further details.

f) Subnetwork structuring: Following the KIKOUT procedure, it is possible that the network has been divided into two or more

subnetworks. For proper operation of the optimization algorithm, it is necessary to identify and optimize each subnetwork separately. Identification of the subnetworks is performed by the SUBNET subroutine.

g) Offset Optimization: Using a technique adapted from the SIGRID Program {8}, the optimum offsets, as given by the offset values associated with the global minimum system performance function, are calculated. It should be noted that this function merely measures the discrepancy between the ideal and calculated offsets, and not the real system performance in terms of delay and stops. However, it does provide a relative indication for performance comparisons of different offset arrays for a given trial system cycle length. All subnetworks are optimized at the current trial system cycle length.

h) Evaluation of the performance of isolated signals: This is accomplished in terms of delay and stops using the technique developed by Webster {4}. Uniform delays and stops for these links are also evaluated using Webster's method. All priority green links, external links and internal links emanating from or entering kicked out signals are processed in this section.

Delays and stops for internal, non-kicked out links are obtained by referencing the delay/difference-of-set curves previously calculated. It is important to remember that all delay and stop values are considered relative indicators and are not necessarily measures of actual on-street performance.

i) System Performance Evaluation: The overall system performance index is obtained by adding the performance index from the isolated signals and the performance index of the coordinated signals. The performance index is a function of both the stops and delays on each link. Following each trial cycle length, the optimum splits and offsets are printed for each intersection, as are individual link performance indicators. After the entire range of candidate system cycle lengths has been processed, a table of total system performance values are printed with the optimum cycle length.

In addition to the previously mentioned constraints, the SSTOP program, as provided, can optimize a network containing up to 60 intersections and 300 links. Even larger networks can be optimized if program dimensions are increased.

2.3 TIME REQUIREMENTS

Although complete analysis of computing time and manhour requirements have not been performed, indications are that SSTOP is a very efficient package. The example network included as Appendix A of this report comprises 29 intersections and 96 links. For trial cycle lengths of 60, 70, and 80 seconds a total of 47 seconds of execution time was required when operating on a CDC 6400 computer at the lowest level of compilation on the program. Execution times on the CDC 7000 series and on the IBM 300 series are even faster. Computing time is approximately a linear function of the number internal links in the

network. Initial indications are that a network consisting of 30 signals and 120 links can be optimized for five cycle lengths for a cost less than $20.

2.4 PROGRAM SPECIFICATIONS

SSTOP assumes that the input file unit number is 5 while the output unit file number is 6. In addition, a temporary working file, with unit number 25 is also required. These three parameters may be altered by replacing the three cards immediately following the COMMON statements in the main program of SSTOP. The scratch file unit number is set using the statement NDRUM = 25, the input file number by R = 5 and the output by P = 6. All further file references are made by employing the appropriate variable name.

The current version of SSTOP requires a computer with word size of at least 32 bits. Since the current version of SSTOP has been executed successfully on both CDC and IBM systems new users should experience few difficulties in loading SSTOP onto these or similar systems.

3. INPUT REQUIREMENTS

This chapter provides a complete description of input requirements for the SSTOP program. A complete understanding of the meaning and the limits of each of the variables greatly enhances the effectiveness of the generated signal timing plan. Potential users are therefore strongly advised to carefully examine the requirements and formating of the input data for SSTOP. For those who subsequently become familiar with the program, Section 3.15 provides a synopsis of input requirements.

The input requirements have been kept to a minimum, and in fact, are not much greater than those required for the generation of signal timing plans by manual means. Specifically, only four card types are required for optimization runs with an optional fifth card being provided at the discretion of the user. Of the four card types, Card Type 1 (Title Card) and Card Type 2 (Network Parameters Card) occur only once in the data deck. A Card Type 3 (Link Information Card) is required for each link in the network while a Card Type 4 (Approach Card) is required for each approach. Card Type 5 is reserved for user-specified parameters for fine tuning program default values. Sample coding has been used extensively throughout this chapter to illustrate proper coding and formating procedures. Where possible, the examples employed are taken from the sample network contained in Appendix A. The meaning of the 'I', 'A', and 'F' formats are discussed in the glossary.

Provision has also been made for users wishing to evaluate existing or proposed signal timings using SSTOP. In addition to the previously mentioned card types, it is necessary, for evaluation runs to provide one card type 6 for each intersection specifying the timing plan. The use of the evaluator is discussed in section 3.11. Evaluation results should not necessarily be considered as measures of on-street performance, but can be considered as relative indicators of effectiveness.

Also included in this section is a discussion of the coding requirements for the recent enhancements made to SSTOP by both DeLCan and M.T.C. This includes Card Type 7 for Economic Analysis and Card Type 10 and 11 for Time-Space Diagrams.

3.1 CARD TYPE 1 - TITLE CARD

Card Type 1 allows the user to specify up to 70 alphanumeric characters which will identify the network to the user. This title will then be printed at the head of each page of output. There is only one card Type 1 in the data deck. It appears as the first card.

The input requirements and formats are outlined below and depicted in Figure 3.6.

Columns	Format	Entry
1-5	I5	1 (card type)
6-75	70A1	User Identifiable Title - up to 70 Alphanumeric characters

3.2 CARD TYPE 2 - NETWORK PARAMETERS CARD

Card Type 2 requires various data which are applicable to all or most of the network. The single network parameters card appears as the second card in the data deck. The data requirements and formats are discussed below and illustrated in Figure 3.6. All entries including alphanumeric entries are right-justified in the field.

Columns	Format	Entry
1-5	I5	2 (card type)
6-10	I5	Minimum Cycle Length - the smallest network cycle length, in seconds, to be used in the program. A minimum value of 40 seconds is permitted. (odd numbered cycle lengths are not recommended. Incorrect delay calculations may result.)
11-15	I5	Cycle Length Increment - the step size or increment in seconds between trial cycle lengths. Ten seconds is recommended with a minimum of 2 seconds allowed. A maximum of ten trial cycles per run is allowed.
16-20	I5	Maximum Cycle Length - the largest network cycle length in seconds. A maximum value of 120 seconds is permitted. When only one cycle length is required, the minimum and maximum cycle length is required, the minimum and maximum cycle lengths have the same desired value entered while any non-zero value is entered for the cycle length increment.

Column	Format	Entry
21-25	I5	Maximum Kickout Length - the largest individual cycle length permitted for kicked out signals. There is no upper limit set for this value. Should this value be too low, the degree of saturation for some kicked out signals may exceed 1.0.
26-30	I5	Number of Links - the total number of network links, including external links and priority links (see Section 3.3). The number of links is equal to the number of card type 3's in the data deck. SSTOP is currently set to accommodate up to 300 links. To alter this value, increase program dimensions.
31-35	I5	Number of Intersections (Int'ns) - the total number of signalized intersections in the network. The number of intersections should not exceed 60. Should the network contain more than 60 intersections, increase program dimensions.
36-40	I5	Network Stop Penalty - the network wide measure of the cost associated with a stop, in seconds per stop. The recommended value is 4 seconds per stop. A stop penalty coded in columns 56-60 of the link card (Card Type 3) will override any network of stop penalty.
41-45	I5	Network Clearance Interval - the time, in seconds, allocated for vehicles to clear the intersection following a green display, for the majority of phases within the network. A clearance time value coded in columns 36-40 of link card (Card Type 3) will override any network clearance time.
46-50	A5	Metric Units? - an entry of 'YES' or 'Y' in columns 46-50 will indicate that input units will be metric. If these columns are left blank or a zero entered in column 50, the program will default to imperial units.
51-55	A5	Data Check? - An entry of 'YES' or 'Y' results in a check of the integer fields on card types 3 and 4 to ensure only blanks or digits are contained in the fields. Should any other characters be found in these fields, the card will be printed out with the incorrect entry underlined. Imbedded blanks in a field are also not permitted. That is, blank spaces to the right of a punched column in the same field are not allowed. This check proves useful for ensuring that all entries are right-justified. All cards will be processed, unless they are found to be out

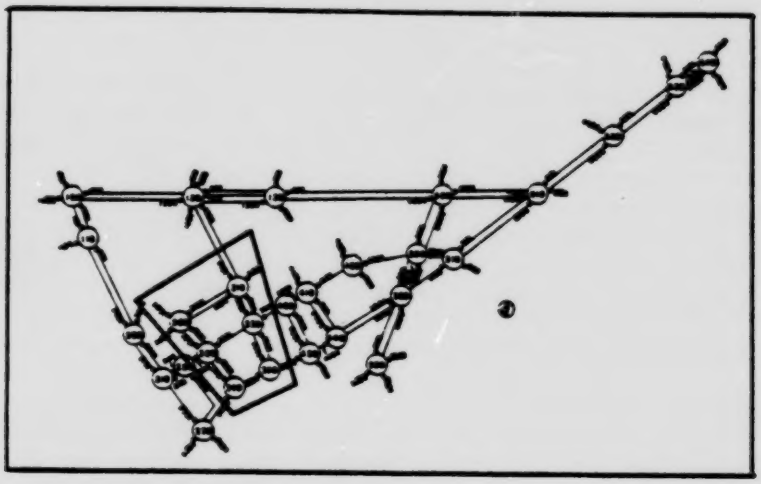
Column	Format	Entry
		of sequence, at which point the program would terminate. This feature is useful for checking a data deck which is being run for the first time. Should this option not be used and an illegal entry discovered, there will be a machine flagged error, followed by termination of the program. See Section E.2 for further details. It is recommended that this option be used only on the first run of the data deck as the checking process is time intensive.
56-60	A5	Evaluation Run? - An entry of 'YES' or 'Y' results in the program being used as an evaluator. Only one cycle length per run can be correctly evaluated. Hence, the minimum (columns 6-10) and maximum system cycle lengths (columns 16-20) should be set to the cycle length to be evaluated. A non-zero cycle length increment should also be entered (columns 11-15) to maintain programming logic. This option is further discussed in Section 3.11.

3.3 NETWORK CODING

The first step in coding the network is to identify all signalized intersections by a number containing up to three digits (Figure 3.1(a)). Next, all links within the network must be numbered. The link number is derived from the intersection number controlling the release flow plus a directional code. The direction code is merely a one digit number attached to the intersection number. It is not necessarily associated with any given compass direction, rather, it indicates which links have flows in approximately the same direction.

A commonly employed system of assigning direction code numbers involves the clockwise numbering of links beginning with the southbound link being indicated by the intersection number followed by a 1, the westbound link by the intersection number followed by a 2 and so on (see Figure 3.1(b)). Should there be more than four approaches at the intersection, the numbering system continues in the clockwise direction. Thus a second eastbound link would be identified by the intersection number followed by an 8. The link direction code may not less than one, nor may it exceed nine. Thus, the total number of neutral links at any intersection may not exceed nine.

It is particularly advantageous to make full use of the clockwise numbering sequence from 1 to 4. It is not necessary that the southbound approach have as its directional code a 1, it could as easily be 2, 3, or 4. However, all links with flow in the same direction should have the same direction code throughout the entire network as this procedure simplifies the coding effort, as discussed below.



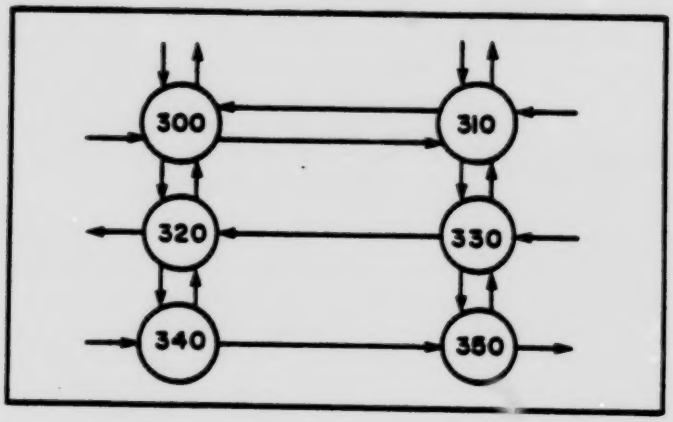


Figure 3.1(a) - Intersection Coding

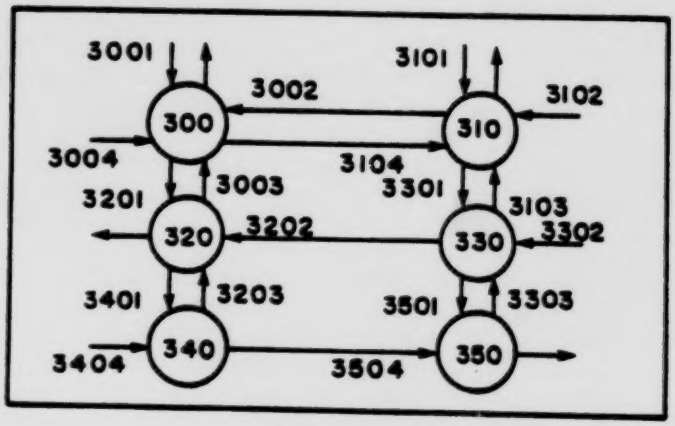


Figure 3.1(b) - Link Coding

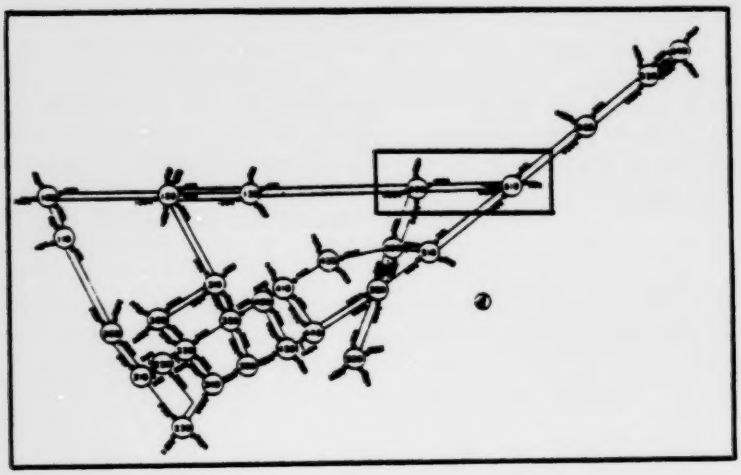
Figure 3.1 - Network Coding

In certain circumstances it may be necessary or desirable to represent an approach by more than one neutral link. For example, if an approach has more than three exit flows, two type 4 cards will be required to provide the program with the complete information regarding turning movements. An example of such a situation is provided in Section A.2 of Appendix A. When two neutral links are used to represent an approach, the links are referred to as parallel links. In such a situation, the designation of card type 4 as the 'Approach' card is not accurate. It is felt that the selected terminology should not cause undue difficulty however. Other instances in which parallel links may prove useful are in 'T' intersection cases (see Section A.3) in which one turning movement is considerably higher than the other, or at intersections which have a double left-turn phase. Any number of links may be designated as parallel provided that the total number of neutral links at any intersection does not exceed nine. Proper coding for parallel links is discussed below.

SSTOP, before offset optimization occurs, combines the importance factors for the parallel links into one value, thereby ensuring that correct weighting is given to the offset of that approach leg (see Section C.3.6 and C.3.7). It should again be pointed out that random delay calculations are performed for each link, and are solely a function of the degree of saturation on the link. Therefore, use of parallel links will likely result in overestimation of the random delay component.

An approach having a priority green indication would be coded as consisting of two links. One of these would be a neutral link while the other would have the same number as the parallel through link, but proceeded by a minus sign for an advanced green (negative link) and a plus sign for a delayed green (positive link) (see links -6104, 6104 in Figure 3.2). A link number with no leading sign is termed a neutral link. It is not permitted to have both an advanced and delayed green in the same phase, although they are allowed in different phases at the same intersection. Each advanced or delayed green indication at a signal is considered as a separate green interval. Thus an approach have a delayed green would have two intervals; the solid through green and the delayed flashing green. An intersection have two phases, one a split-phase, (having an advanced or delayed green indication) would have three intervals. Each intersection within the network may have up to six intervals. Thus, SSTOP may process intersections with say, four phases, two of which may be split-phases.

SSTOP assumes that one hundred left-turning vehicles per hour may be cleared during the clearance interval. This default value may be adjusted through use of Card Type 5 to any desired value (see Section 3.8). Additionally, it assumes for priority greens that a minimum of 15 vehicles per hour remain to be cleared during the green period. Therefore, a rough guideline in determining the locations for priority greens would be that the left-turn volume is at least equal to the number of vehicles cleared during the clearance interval plus 15. This guideline may be waived however if there light opposing flows



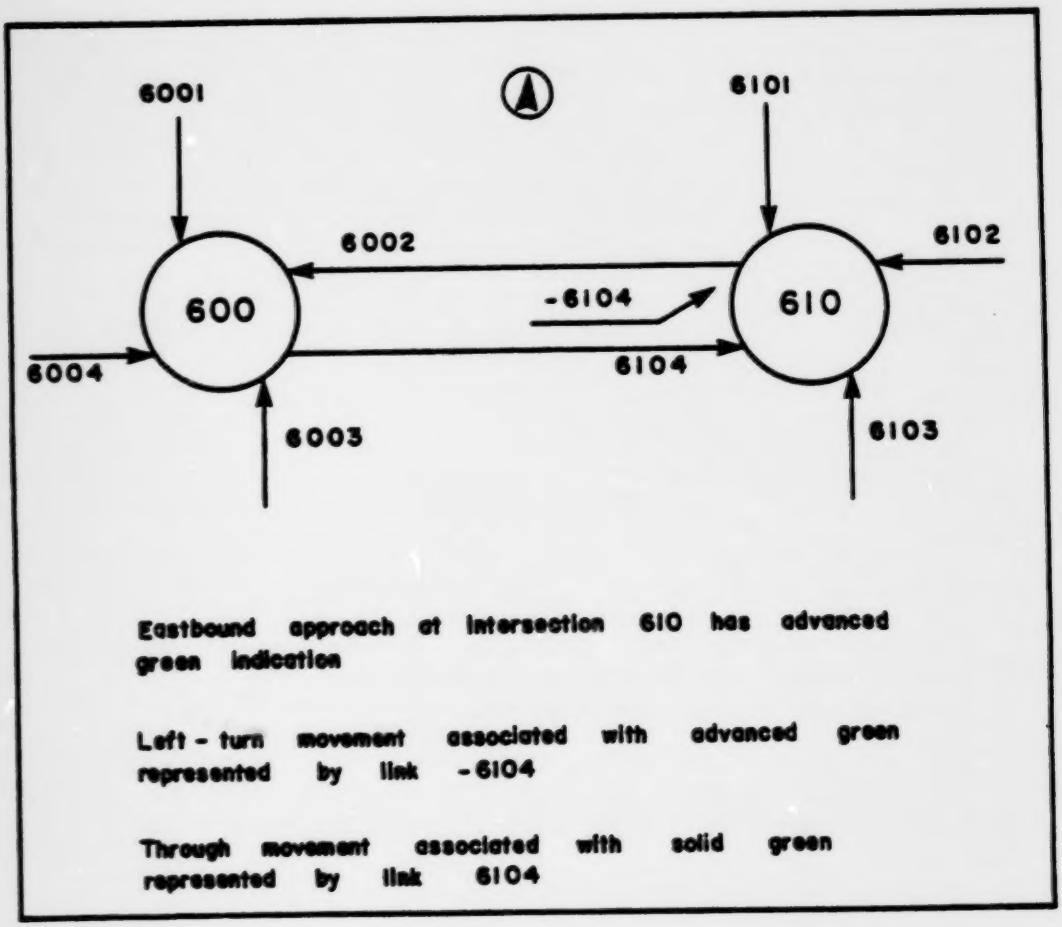


Figure 3.2 Priority Green coding Example

which would permit some left-turns to be made during the solid green period, or if the presence of left-turn vehicles disrupts the flow of through vehicles (as in the case of shared lanes). SSTOP also assumes that the clearance time, if any, between the flashing green interval and the solid green interval is in fact available to the neutral link parallel to the priority left-turn link for release of vehicles, but not to the left-turn or opposing links.

To simulate traffic flow patterns within the network for purposes of generating delay/difference-of-offset curves, the SSTOP algorithm requires the internal identification of all links which feed into the link currently under investigation. The hypothetical subnetowrk depicted in Figure 3.3 will be used as an example to illustrate this concept.

Link 103 has link numbers 202, 203, and 204 as source links (those links which have flows entering the upstream end of link 103). More specifically, link 103 has as source flows the left turns from link 204, the through movement from link 203 and the right turns from link 202.

It is not usually necessary to specify these source links as SSTOP performs the following operations in constructing the source links and obtaining source link flows if no source link information is provided on card type 4. First, it constructs the source link numbers. These are correctly obtained from the upstream intersection number (provided on card type 4), assuming the recommended link directional code has been adopted. For link 103 the upstream intersection is 20. Hence the source links and flows are automatically assumed to be left turns from link 204, through movement from link 203, and right turns from link 202. A scan is then made of the link list to ensure that these links do actually exist in the network. The program also checks for the existence of priority left-turn links and accounts for them if they are present. A similar procedure would be applied to all links having direction codes 1-4. Those links with directional codes 5-8 do not have this default option available except for the parallel link situation discussed below. For more complex network configuration, the user may be required to specify the source links.

In the example of Figure 3.3 the network is not a normal grid configuration (where source link codes do not have to be entered as input). The assumed source code convention will no longer apply for several of the links; in this case links 102 and 301. Standard convention assumes that link 102 should receive through movements from link 302. Due to the triangular configuration, this is not the case. Rather, link 102 receives right turns from link 302, a through movement from link 303, and left turns from link 304. To provide this information to SSTOP, the user must input these source links on card type 4. This procedure is further discussed during the card type 4 description (Section 3.7).

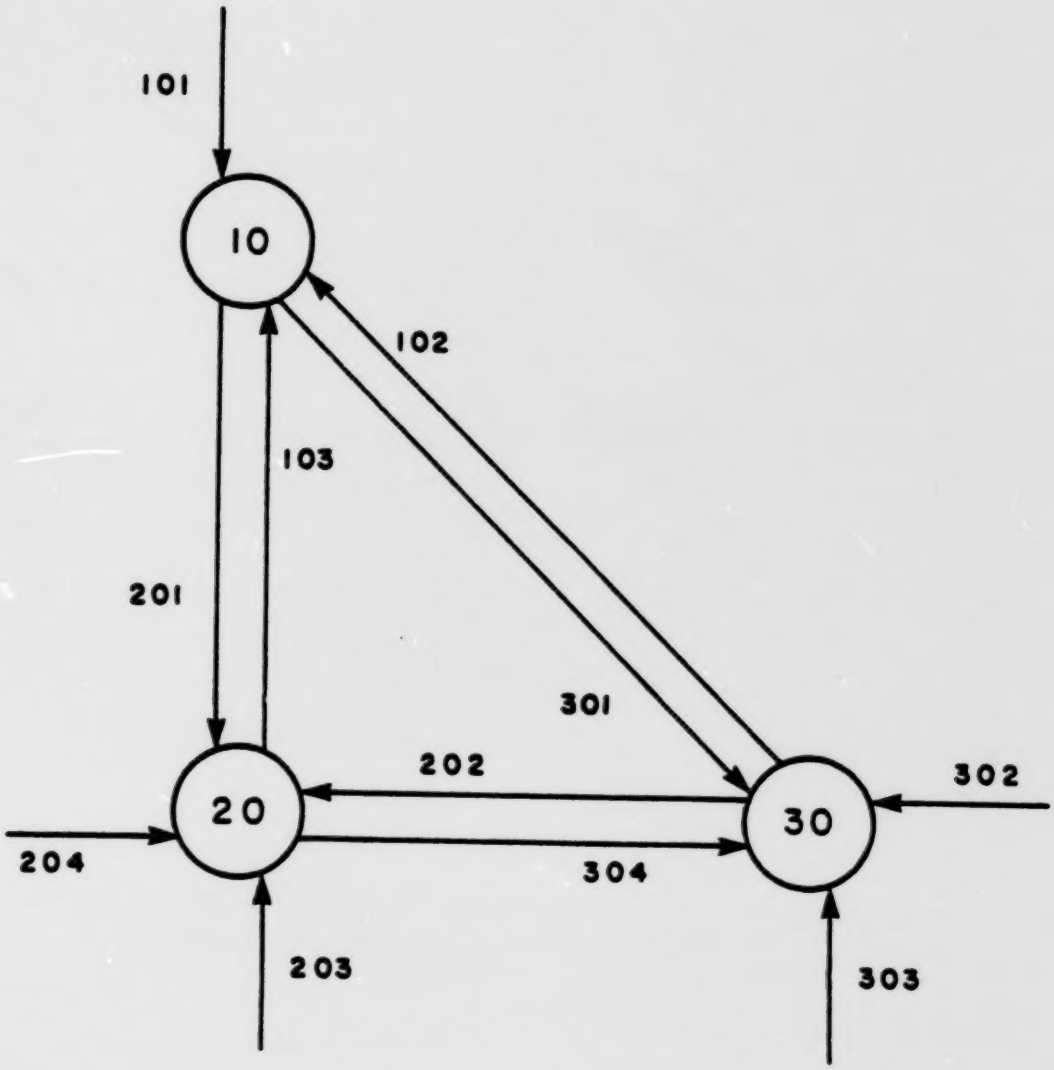


Figure 3.3 Source Link Coding Example

Suppose now that link 202 in Figure 3.3 was a 'T' intersection; that is only left and right turns are permitted from this link. If there are two left-turn lanes with a saturation flow of 3000 vehicles per hour and a volume of 1200 vehicles per hour, and corresponding right turn figures were 3000 and 300 respectively, then a single link representation would indicate that this approach has volume/saturation flow (V/S) ration of 0.25 {from (1200+300)/(3000+3000)}. However, the left-turn lanes actually have a V/S ratio of 0.4 (1200/3000). Thus a single link representation would underestimate the green time requirements of the left-turning vehicles. A parallel links representation is therefore advantageous. Link 202 may represent the left-turn lanes while a link 206 (not shown on Figure 3.3) may be used to represent the right-turn lanes. Specification of the same upstream intersection, link length and design speed, on card type 4 (Section 3.7) for both link 202 and 206 indicates to SSTOP that links 202 and 206 are indeed parallel. For link 206, then, it is not necessary to specify source links providing the data cards for link 206 follow those for link 202. SSTOP, upon discovering a link having a direction code greater than four with an upstream intersection will, if no source links are specified, trace back through the link list until the parallel link is found, and will assign the same source links. For this reason, the parallel link with direction code 1-4 must occur before the parallel link with direction code 5-8 in the data deck, as previously indicated.

Should a situation occur in which parallel external neutral links exist, in addition to a priority left-turn link, a slightly different coding procedure must be used to indicate that the neutral links are parallel. For the neutral link not having the priority left-turn associated with it, it is necessary to enter in the upstream intersection field of card type 4 the other neutral link number, proceeded by a minus sign. The minus sign identifies this entry as being a parallel link number and not an intersection number. This coding convention is required only for those cases in which two neutral links and one priority left-turn link are parallel, external links to assist in properly calculating the critical volume/saturation flows for each green interval and hence the cycle lengths. See section C.2.1.2.

3.4 SEQUENCING OF CARD TYPES 3 AND 4

Card Type 3 (Link Information Card) and Card Type 4 (Approach Card) provide SSTOP with the detailed information necessary for generation of an effective signal timing plan. In the majority of cases the intersection approach characteristics and the approach leg characteristics may be fully described by providing the data requested on one each of Card Types 3 and 4. For those approaches which have a priority left-turn green indication, the roadway section utilized by left-turning vehicles is represented by one link while the roadway section used by the through the right turn movements is represented by another link. To properly simulate the priority left-turn, it is required to submit two type 3 cards and one type 4 card for these approaches. The through link and left-turn link will both have the same link number. However, the left-turn link number must be preceeded by a negative sign to indicate an advanced left-turn movement. A positive sign preceding the number indicates a delayed

left-turn green. A coding procedure similar to that of the advanced left-turn green is adopted.

Data deck structure requires that the type 3 cards immediately proceed the equivalent type 4 card in the data deck. All non-neutral type 3 cards must preceed the corresponding neutral type 3 card in the data deck. All groups of Card Types 3 and 4 for any intersection must appear sequentially in the data deck as well. To illustrate these concepts and procedures, the card coding and sequencing necessary to represent the two intersections illustrated in Figure 3.2 is given in Figure 3.4.

As indicated by the discussion in the previous section, if parallel links are used and no source link are entered for the link with direction code greater than four, the link having a direction code less than or equal to four must occur first in the data deck.

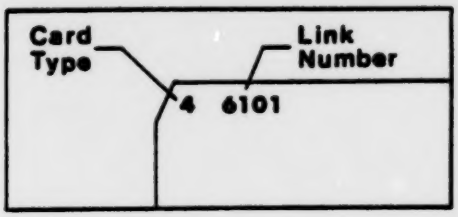
3.5 FLOW SPECIFICATION AND UNITS

SSTOP provides the capability for entering saturation flows and volumes in various methods. In all cases, however, these parameters must be expressed in hourly units.

The most general application of saturation flow is obtained when units are expressed in through car units per hour of green (tcu/hr.-grn.). Expression of saturation flow in these units makes it independent of any vehicle, flow or signal characteristics. For this reason the, saturation flow is assumed to be in tcu/hr-grn. Section B.1 provides an outline of several techniques by which saturation flow may be determined. For approaches which are very much undersaturated, it is normally sufficient to estimate saturation flow using one of the empirical approaches. Otherwise, it is recommended that saturation flow be measured on street for best results.

Traffic volumes are intended to be input in units of vehicles per hour. Passenger car unit (pcu) and through car unit (tcu) conversion factors are applied to these values. The passenger car unit conversion factor converts trucks and buses into equivalent passenger car units while the through car unit factors convert left and right-turning passenger cars into equivalent through car units. The resulting value is then divided by the saturation flow to obtain the volume to saturation flow ratio.

Engineering judgement should be exercised in the compilation of the volume data to be employed as input. Traffic volume counts are invariably taken during the summer months when total volumes are generally lower than during the remainder of the year. It would therefore be advisable to consider applying a scaling factor to the volume data available to account for the difference between summer volumes and those in the remainder of the year.



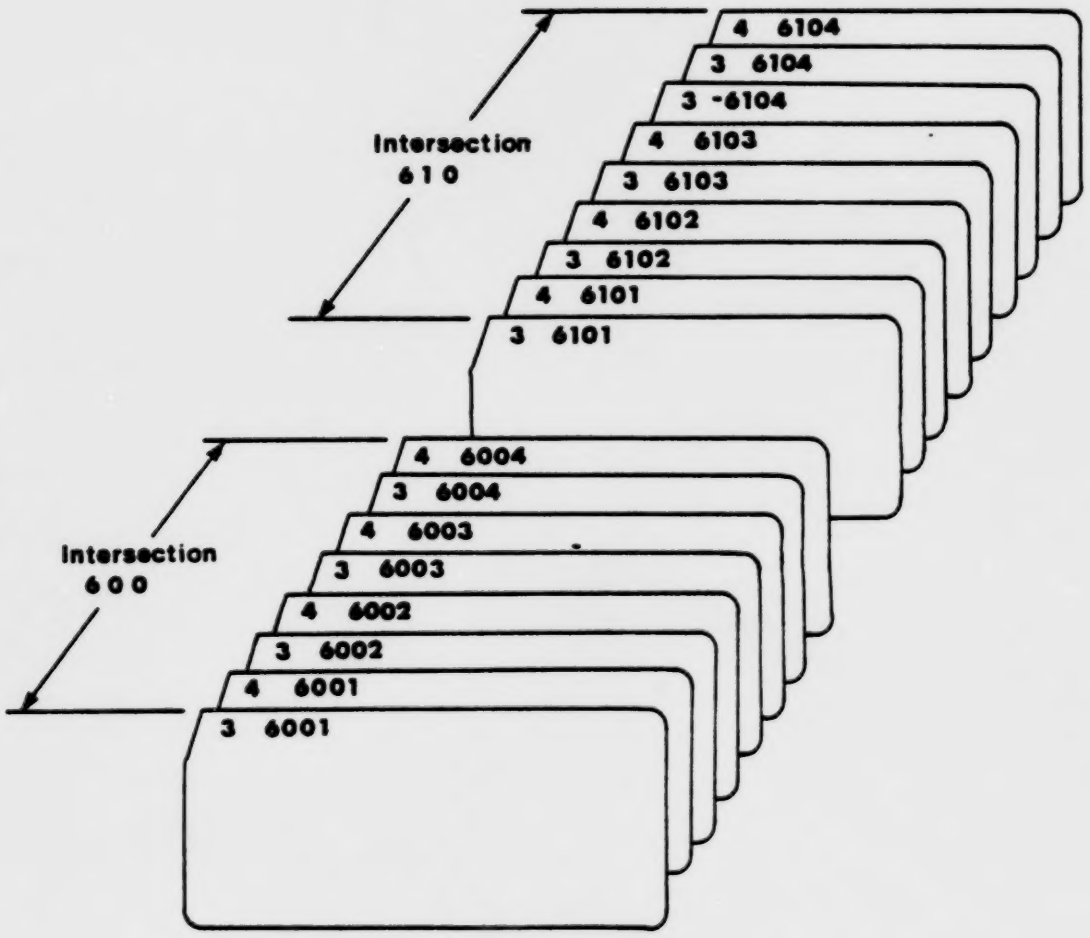


Figure 3.4 Card Type 3 and 4 Sequencing

If only one-hour volume counts are available, consideration should also be given to employing the peak fifteen-minute volume times four instead of the average hourly volume. This technique will however result in overdesign of green times for much of the time period under consideration. Again engineering judgement must be exercised.

Similar considerations should also apply to saturation flow values. More specifically, saturation flow values will be much lower in the winter when lane markings are worn or obscured or when snow is in the curb lanes, than in the summer months. Further, in applying any empirical saturation flow estimation techniques, consideration should also be made of actual driver behaviour. For example, on one-way streets, curb lanes are not utilized as fully as centre lanes. Factors such as this would result in lower saturation flow values than indicated by the empirical methods.

The pcu and tcu conversions are required to provide SSTOP with an indication as to the impact of a left or right-turning vehicle on the traffic stream. A left-turn tcu figure of 1.75 indicates that a left-turning passenger car requires 1.75 times as much green to clear the intersection as a through passenger car. A value of 2.00 for the truck and bus pcu indicates that a truck or bus requires twice as much green time to clear the intersection as a passenger car making a similar movement. Thus a left-turning truck requires 2.00 x 1.75 = 3.50 times as much green as a through passenger car.

The following assumptions have been made in SSTOP regarding the pcu and tcu conversions.

- one truck or bus = 2.0 passenger car units.
- one left-turning passenger car = 1.75 tcu subject to the provisions outlined below.
- one right turn passenger car = 1.25 tcu subject to the provisions outline below.
- an exclusive left or right-turn bay or lane indicates that the tcu conversion factor for that movement is 1.0.
- at a T intersection, those vehicles exiting from the stem of the T are assigned left and right tcu conversion factors equal to 1.0.
- on a one-way street, the left-turn tcu conversion factor is set equal to the right-turn tcu factor subject to the existence of exclusive lanes.

Should the passenger car unit or through car unit conversions be unsuitable for the network under consideration, it is possible through use of the optional Card Type 5 to alter these parameters to any value greater than or equal to 1.0 (see Section 3.8). Also it is now possible to directly specify the conversion factors for any individual intersection on Card Type 3. The Specification of geometric features (left or right-turn bays, T-intersections, one-way streets) is made on card type 4, columns 26-30 (Section 3.7) and overides the link specific conversion factors coded on Card Type 3.

An alternate technique by which saturation flows and volumes may be specified for SSTOP is to input these terms with identical units, most probably vehicles per hour of green and vehicles per hour respectively. Use of such a technique requires that all passenger car and through car unit conversion factors be set to 1.0 by use of the optional card type 5 (Section 3.8). It is then no longer necessary to specify truck and bus percentages (columns 46-50, card type 4) and geometric features (columns 26-30, card type 4).

This technique provides the user with sufficient flexibility to employ any saturation flow and volume units with which he feels comfortable. The user must understand the operation of the program with regard to saturation flow and volumes completely if the network is to be properly dealt with by SSTOP.

3.6 CARD TYPE 3 - LINK INFORMATION CARD

Card type 3 (Link Information Card), as it names implies, contains all link oriented information. This includes a user identifiable link name, the signal phase number controlling outflow from the link, saturation flow, minimum green and clearance time. One card type three is required for each link (internal and external) within the network.

Data requirements and formats are outlined below. Example coding is provided in Figure 3.8. All entries, except for the user identifiable link name and the count column entries must be right justified in the field. The link name may be located anywhere within the field.

Column	Format	Entry
1-4	I4	Count Column - these columns are provided to allow the user to number the input data cards to assist in structuring the data deck. SSTOP does not read these columns.
5	I1	3 (card type)
6-10	I5	Link Number (See Section 3.3)
11-20	A10	User Identifiable Link Name - this link name is printed in each section of link oriented output to provide a more suitable method of link identification. Although no specific format is necessary, the use of a basic 7-character link name, composed of a 5-letter cross-street name, followed by the first letter of the approach plus a directional code has proved successful. The remaining three columns may be used for additional comments such as advanced or delayed green indications or double left-turn specification. For example, the link name contained in Figure 3.6 identifies the southbound approach (S) on Ontario St. (O) with Welland (WLLND) as the cross-street.

Column	Format	Entry
21-25	I5	Phase Number - the order of appearance of a particular phase relative to the main-street or offset phase, the value entered in these columns for this green would be the same as the value entered for the parallel neutral link of the following card type 3.
26-30	I5	Saturation Flow - the maximum rate, usually in through car units per hour of green (See Section 3.5), at which vehicles enter the intersection after the queue start-up delay has been eliminated and while a continuous demand exists (also see Section B.1). The value entered for priority greens would be that value pertaining only to the left-turn movement.
31-35	I5	Minimum Green - the minimum allowable green time, in seconds, for a particular approach link. For neutral links, it is usually governed by the minimum pedestrian walk time across the widest perpendicular approach leg. This value should be the same for all neutral links associated with a particular phase. If they are not, SSTOP uses the value from the link which it determines to be critical in that interval. For priority green intervals this value can be of any length, but should include any solid green clearance times.
36-40	I5	Clearance Time - an entry here overrides the network clearance time entered in columns 41-45 of the network parameters card (card type 2). See section A.6 for an example of this override procedure. All links associated with any one phase, except in split-phase operation, should have the same clearance time. SSTOP employs only the clearance times from the critical approach in its optimization routine. The values entered here will be assumed to be the length of the amber or amber plus all red period following the particular phase. To simulate the actual use of the green period by traffic (effective green) it would be more exact to input the lost time (green + clearance interval - effective green) in these columns. A manual alteration of the final signal settings would then be required to provide actual timings. Generally, however, clearance time should be an adequate estimation of this lost time.
41-45	F5.0	LEFT TURN TCU CONVERSION FACTOR - this value is multiplied by the left turn volume to obtain equivalent tcu volume.
46-50	F5.0	RIGHT TURN TCU CONVERSION FACTOR -

Column	Format	Entry
		this value is multiplied by the right turn volume to obtain equivalent tcu volume.
51-55	F5.0	TRUCK/BUS TCU CONVERSION FACTOR - this value is multiplied by the truck/bus volume to obtain equivalent tcu volume.
56-60	I5	STOP PENALTY FACTOR - this value is multiplied by the number of vehiclar stops and added to link delay to obtain a representative link performance index.

3.7 CARD TYPE 4 - APPROACH CARD

Card type 4 (Approach Card) contains information relating to the approach or the approach leg. This includes some physical characteristics of the approach as well as the traffic characteristics. There is one card type 4 for each neutral link in the network. Placement in the data deck is described in section 3.4. All entries must be right justified in the field. Figure 3.8 illustrates the required input data and their formats. Explanation of the input parameters follows.

Column	Format	Entry
1-4	I4	Count Column - these columns are provided to allow the user to number the input data cards to assist in structuring the data deck.
5	I1	4 (card type)
6-10	I5	Link Number (See Section 3.3)
11-15	I5	Upstream Intersection - the number of the signalized intersection controlling inflow to the link. External links have no upstream intersection.
16-20	I5	Link Length - the distance in either feet or meters (depending upon specification on card type 2 columns 46-50) from the upstream intersection to the stop bar of the approach. External links have no link length.
21-25	I5	Design Speed - the speed of travel in miles or kilometers per hour (depending upon specification on card type 2, columns 46-50) which a vehicle could maintain between two successive stop lines on a specified link assuming no delays were occassioned as a result of signal timing. Implicitly it does include the effect of such factors as land use, parking, volume etc. SSTOP

Column	Format	Entry
		calculates ideal link offsets, and ultimately, optimal network offsets using this value. Effectively then, the design speed is the desired running speed of the link. See definition in Glossary and Section B.2 for more detailed discussion. External links have no design speed.
26-30	A5	Geometric Features - indicates the existence of any special physical features on the approach. These features are used to determine the proper tcu conversion factor which should be applied to the approach (see Section 3.5). The following entries are permissible, with only one entry allowed per approach. These values override the link specific conversion factors coded in Card Type 3. Left or L - indicates an exclusive left-turn lane or bay. Left-turn tcu = 1.0 RIGHT or R - indicates an exclusive right-turn lane or bay. Right-turn tcu = 1.0 BOTH or B - indicates an exclusive left and right-turn lanes or bays exist. Left-turn tcu = 1.0. Right-turn tcu = 1.0 T - indicates a T-intersection exists (entered only for the approach forming the stem of the T). Left-turn tcu = 1.0, Right-turn tcu = 1.0 ONE - indicates a one-way street. Left-turn tcu = Right-turn tcu. For the first three entries, the exclusive turning bay should be adequate to store all turning vehicles for most cycles.
31-35	I5	Number of Left Turns - the number of vehicles which turn left during the design period. Due to rounding within the program, this value will be set to zero if it is less than one percent of the total volume in columns 31-45. For priority green periods this value should not be less than 15 vehicles plus the number of left-turn vehicles cleared during the clearance interval (see Sections 3.3 and 3.8).
36-40	I5	Number of Thru Vehicles - the number of vehicles which move straight through the intersection during the design period.
41-45	I5	Number of Right Turns - the number of vehicles

Column	Format	Entry
		which turn right during the design period. Due to rounding within the program, this value will be set to zero if it is less than one percent of the total volume in columns 31-45. The sum of the volumes in columns 31-45 must be greater than zero. If the volume/saturation flow (V/S) ratio for a link is less than 0.01, SSTOP assumes the V/S ratio to be 0.01. Thus the total tcu volume in columns 31-45 should be at least one percent of the saturation flow ratio.
46-50	I5	Percent Trucks and Buses - the percent of the total approach volume consisting of trucks or buses (vehicles with more than 4 wheels) during the design period.
51-55	I5	Importance Factor Multiplier - This field should be left blank except for very special circumstances. If a blank or zero entry is made in these columns, SSTOP will assume a default value of 10, which results in unity weighting for the link. The base of 10 is employed to allow fractional input without the use of real numbers; the use of which increases program execution time. If for example, the importance of one link is twice that of all others then a value of 20 would be entered in these columns. The importance factor multiplier may be used to improve offsets on links which have low volumes, but for various reasons, may require good offsets. The higher the link's importance, the more likely it will be to have its offset set equal to the ideal offset as calculated by SSTOP (see Section C.3.5). Additionally, the multiplier may be used to crudely simulate exclusive transit lanes in which the stoppage of one vehicle is much more critical than on normal links. It is strongly advised that the importance factor multiplier not be used on initial optimization runs for a network, and thereafter used sparingly, if at all. Again, the importance factor multipliers are relative to each other; setting them all to 100 would have the same impact as setting them all to 1000 or leaving them at 10. Use of this feature should be made only after thoroughly reading section C.3.2-C.3.7.
56-60	I5	Left Turn Source Link - the link number from which left-turning vehicles enter the upstream end of the link under consideration. All source links

Column	Format	Entry
		must be specified if any entry is made in this or any of the following three fields. This and following entries are required only where nonstandard arterial systems exist, for example triangular configuration (see Section 3.4) or five-legged intersections. Further examples of these situations are given in Appendix A. Only neutral link numbers can be entered in this and the following columns as SSTOP identifies any priority links automatically and assigns them as required.
61-65	I5	Thru Movement Source - the link number from which the through vehicles enter the upstream end of the link under consideration.
66-70	I5	Right Turn Source Link - the link number from which right-turning vehicles enter the upstream end of the link under consideration.
71-75	I5	Fourth Source Link - this and the next entry are required only in situations in which a link has four source links. The fourth source link number is entered in these columns.
76-80	A5	Movement From 4th Source - used in conjunction with the previous field. An acronym specifies which traffic flow movement of the previously specified link enters the upstream end of the link under consideration. The permitted acronyms are: LEFT or L THRU or T RIGHT or R These acronyms are used as follows: an entry of Left or L would indicate that the volume entered in columns 31-35 of card type 4 for the source link specified in columns 71-75 flow into the upstream end of the link under consideration. Similarly, for Thru, (T) and Right, (R) (see section A.1 and A.5 for example coding).

3.8 CARD TYPE 5 - OPTIONAL USER PARAMETERS

Card type 5 is an optional card which, if provided, follows the last card type 4 in the data deck. It allows the user to alter the network wide passenger car and through car unit conversion factors as discussed in Section 3.5. Additionally, the user may specify the number of left-turning vehicles which are cleared during the clearance interval. SSTOP assumes that one hundred vehicles per hour can turn left during the amber period. For advanced or delayed greens, additional green time requirements are calculated once this value of 100 has been deducted from the left-turn volume. For a priority left-turn movement, at least 15 vehicles per hour are assumed to

utilize the green period, after discounting for those vehicles cleared during the clearance interval. In other words, if there are less than 100 vehicles per hour turning left, a priority green should be provided only after careful consideration. Should the value of 100 not be suitable for the network under consideration, an alternative value may be specified on card type 5. Provision is also made to allow the user to enter a more suitable platoon dispersion constant. Sections B.3 and C.3.4 provide a detailed description of this parameter which is the product of the α and β parameters in Robertson's model {5}.

The input data requirements and formats are outlined below and illustrated in Figure 3.8. Only those values to be changed need be entered on this card; default values are assumed for the remainder.

Column	Format	Entry
1-5	I5	5 (card type)
6-10	F5.0	Left Turn tcu - a minimum value of 1.0 is permitted. It is recommended that no more than two decimal accuracy be used. Default = 1.75
11-15	F5.0	Right Turn tcu - Minimum of 1.0, Default = 1.25
16-20	F5.0	Truck and Bus pcu - Minimum of 1.0, Default = 2.00
21-25	I5	Vehicles cleared in Amber - the number of vehicles per hour which turn left during the clearance interval. This value must be a network average. Default = 100 vehicles/hour.
26-30	F5.0	Platoon Dispersion Constant (see Sections B.3 and C.3.4). Default = 0.25
31-35	I5	Optional parameter - JCYCLE. If there is any integer entered here (except 88888, 99999 and zero), the run will be terminated after the cycle length calculations.
36-40	F5.0	VOLUME ADJUSTMENT FACTOR - this value is multiplied by the coded link volume to obtain the modified volume. It may be used to predict future year volumes or may be used as a scaling factor as discussed in Section 3.5.

Column	Format	Entry
41-45	F5.0	MINIMUM GREEN ADJUSTMENT FACTOR - this value is multiplied by the coded link minimum green. Minimum green values are generally based on pedestrian crossing speed and often determine the length of side street green phases. The sensitivity of the optimum network performance index to minimum green constraints can be monitored using this policy.
51-55	I5	TSNUM - if blank or zero, no diagrams will be printed; otherwise TSNUM is the number of diagrams per cycle length; no limit.

3.9 Card Type 7 - Economic Analysis

A user selectable option for determining potential benefits from traffic network improvements has been added to the SSTOP program. Annual benefits due to a reduction in vehicular fuel consumption are compared to the cost of the improvement using either the net present worth method or the rate of return method. This section describes the logic for this option.

The determination of vehicular fuel consumption under different signal timing scenarios is a valuable tool for determining potential traffic network benefits. Several existing signal optimization computer programs contain this feature.

The TRANSYT 7F model employs a fuel consumption model developed by Robertson [17] which is based on average vehicular delay and stops at an intersection:

$$F = K_1\ TT + K_2\ D + K_3\ S$$

where F = fuel consumed in litres per hour
TT = total distance travelled in vehicle-kilometres per hour
D = total delay in vehicle-hours per hour
S = total stops in stops per hour
K_i = coefficients of regression, which are functions of free speed.

The traffic simulation package of TRANSYT 7F provides information concerning vehicular delay and stops at each intersection approach. Using the above expression, a representative measure of fuel consumption is calculated for each candidate signal timing plan.

In addition to computer programs which determine fuel consumption, a matematical model has been developed by Evans and Herman {18}. Fuel consumption is determined based on average vehicular speed:

$$\emptyset = K_1 + K_2/V \ , \qquad V = 35 \text{ mph}$$

where $\emptyset$ is fuel consumption (litres per mile)

K_1 is a fuel dependent paramenter associated with fuel consumed to overcome the rolling resistance and is approximately proportional to the weight of the vehicle.

K_2 is a vehicle dependent parameter (litre per hour) approximately proportional to idle fuel flow rate.

v is the average speed in kilometres per hour as measured over a distance.

The methodology has also been employed to determine vehicle emissions in networks {19}, including carbon monoxide, hydrocarbons and nitrogen oxides.

Based on the above review, the following outputs from SSTOP can form a basis for determining vehicular fuel consumption:

- delay (tcu-hrs/hr)
- tcu stops per hour
- travel time (tcu-hrs/hr)
- average speed (kph)

These values are provided in individual link and in network summary form.

Two methods of determining average link delay and stops are employed by SSTOP:

- For external links, those which do not have an upstream intersection in the network, the following expression for average delay by Webster {4}, is used:

$$d = .9 \times (C(1-G/C)^2/2(1-Y) + ((Bn/Bd)^2 + (x^2/Bd)))^{\frac{1}{2}} - Bn/Bd$$

where: d = average delay per vehicle (hours)
C = cycle length (seconds)
G = green time for the link (seconds)
x = degree of saturation (qc/SG)
Y = volume-saturation flow ratio for the approach
$Bn = 2(1-x)_2 + xz$
$Bd = 4x - z^2$
$z = (2x/v)$

Based on the above equation, the total hourly delay is computed as follows:

$D = q \times d$ (tcu - hrs/hr) , q = average hourly volume (tcu/hr)

The proportion of vehicles (E), on external links, which are stopped at least once by the signal is given by:

$$E = N/C(1-y)$$

where $N = \text{Max.}\ (C-G, \frac{C-G}{2} + d)$

The total number of stops (T) during one hour is therefore given by:

$$T = 3600 \times q \times E$$

- For internal links, the effect of signal offsets on delay and stops is simulated using link exit histograms (Figure 3.5). For each offset, an arrived and departure pattern is constructed, and resultant link delays and maximum queue lengths are obtained. An additional delay value, called random delay (R), models the effect of random fluctatons in link volumes. This value is based on the second term of Webster's delay equation:

$$R = ((Bn/Bd)^2 + (x^2/Bd))^{\frac{1}{2}} - Bn/Bd$$

Where Bn, Bd, z, x, as for external links (see previous page)
V = volume on link (vph)

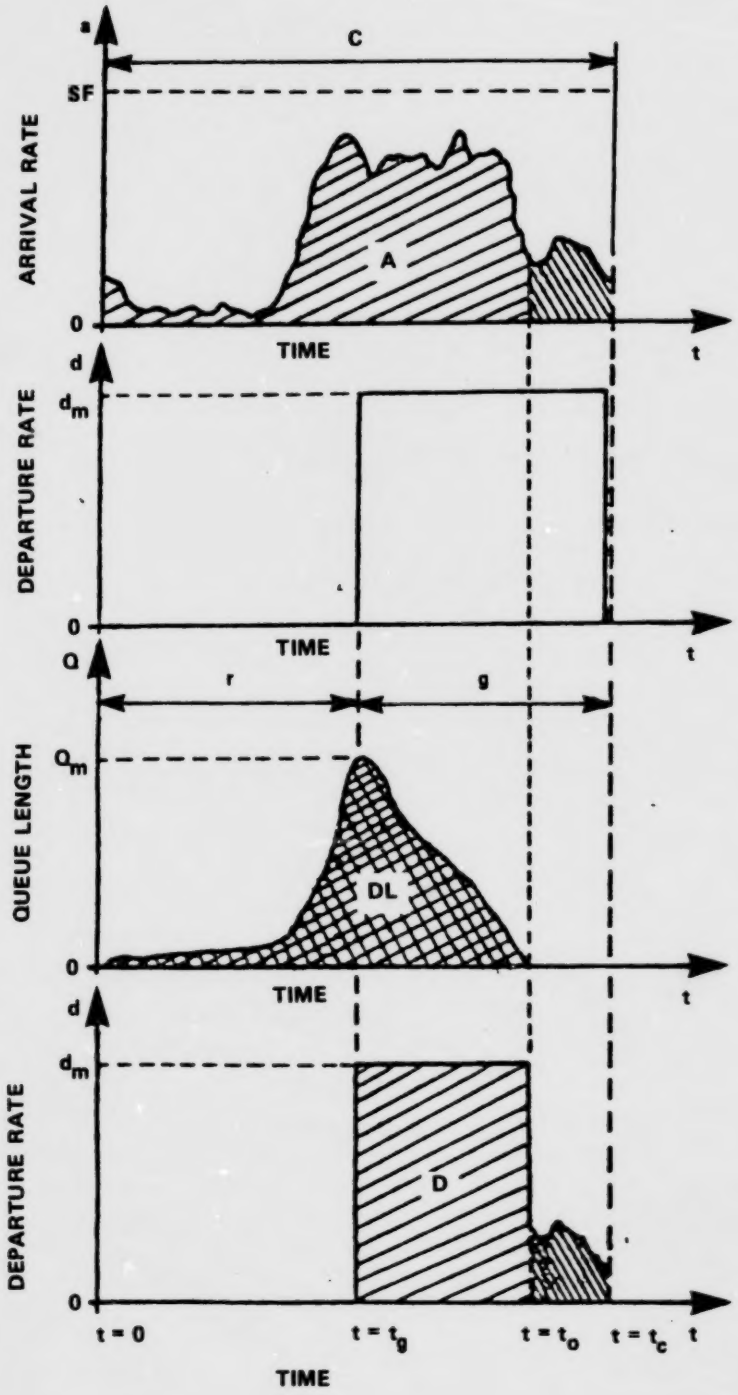
The thrid SSTOP output which can be used for determining fuel consumption is travel time (TT):

$$TT = L/(DS \times 1000) \times q + D + R \text{ (tcu - hrs./hr.)}$$

where L = link length (m)
DS = design speed (kph)
q = volume (tcu)
D = uniform delay (veh-hrs/hr)
R = random delay (veh-hrs/hr)

Due to lack of information concerning link length and design speed, travel time is not determined for external links.

Based on past experience, external links constitute a significant portion of many signal networks, expecially urban arterials. A fuel consumption methodology which would ignore these links would be of marginal use.



LEGEND

t	=	Time
a	=	Arrival Rate
A	=	Cumulative Arrivals
SF	=	Saturation Flow
d	=	Departure Rate
D	=	Cumulative Departures
d_m	=	Maximum Departure Rate
Q	=	Queue Length
Q_m	=	Maximum Queue Length
DL	=	Delay
C	=	Cycle
r	=	Red Interval
g	=	Green Interval

Figure 3.5 Link Departure Pattern

The final SSTOP produced value which can be used for fuel consumption is average speed along a link (AS):

$$AS = (L \times q)/(TT \times 1000) \quad (kph)$$

where L, q, TT are as defined above.

As with travel time, average speed can be deterimned only for internal links. Consequently, it is of limited use in determining network fuel consumption.

Of the four SSTOP outputs discussed, only delay and stop values are calculated for every link in the signal network. However, these parameters model the factors affecting fuel consumption at the intersection approach and cannot provide a basis for evaluating fuel consumed while travelling along a link.

In view of the above deficiencies with average speed and travel time data, it was decided to utilize only delay and stops in determining fuel consumption. The fuel consumption algorithm employed by SSTOP is based on a modified form of Robertsons expression:

$$F_1 = K_2 D + K_3 S$$

where F_1 = fuel consumed due to signal timing (litres per hour)
D = total delay in vehicle-hours/hour
S = total stops in stops per hour
K_i = regression coefficients

This expression provides a measure of the vehicular fuel consumption which is dependent on the signal timings. The additional fuel consumed while travelling along links is independent of any signal timing plan scenario and its deletion in this expression is not important for assessing various scenarios.

The optimization of signal timings will continue to be based on delay and stop measures. These measures can be made sensitive to fuel consumption by adjusting the stop penalty factor. The fuel consumption measures will be employed as an additional evaluation tool available to the traffic engineer. This approach ensures consistency with the existing SSTOP optimization methodology.

The regression coefficients used in the fuel consumption model are representative of light duty vehicles. These values are proportionate to the design speed of the individual link, as shown in Figure 3.6 [20]

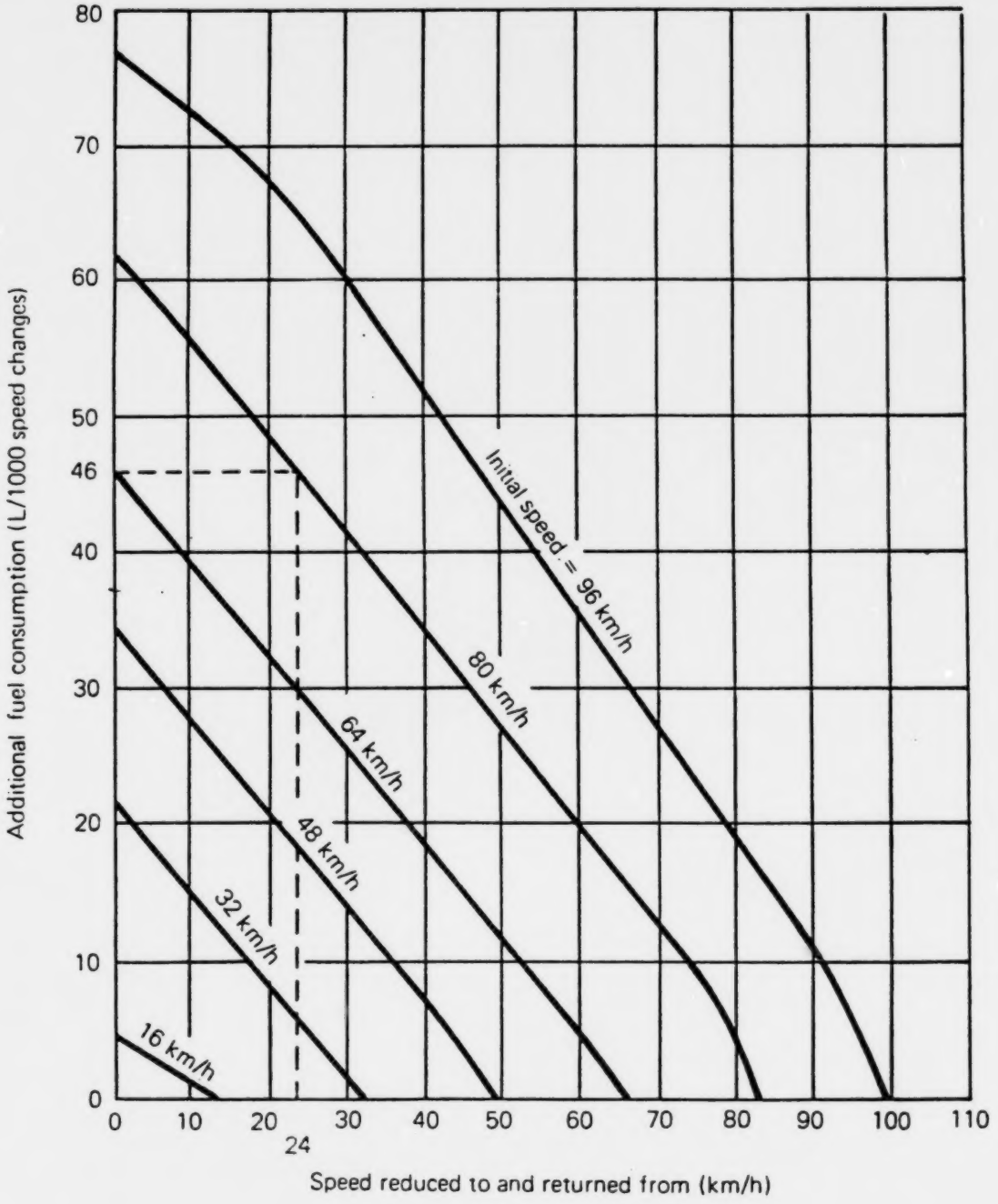


Figure 3.6 Additional Fuel Consumption Due to Speed Changes

The level of improvement in the transportation network resulting from a capital expenditure is determined from the excess fuel consumed during the time period under consideration. This value is compared to a 'base condition' fuel consumption to obtain the potential fuel savings. An equivalent annual fuel saving is calculated using a user provided multiplier and this is transformed into a monetary value.

If the net present worth method is selected, the net present worth of benefits is obtained using the following equation:

$$PWB = AB \times ((1 + i)^n - 1) / i(1+i)^n$$

Where

PWB = Present Worth Benefits ($)
AB = Annual Benefits ($)
i = Discount Rate (%)
n = Project Life (Yrs.)

The present worth benefits are finally divided by the present worth costs to obtain a representative benefit/cost ratio.

If the rate the return method is selected, a discount rate is calculated which results in the benefits of the improvement being equal to the costs. Beginning at a discount rate of .5%, the net present worth of benefits is calculated and compared with the net present worth costs. This comparison is repeated, at increments of .5% until the costs exceed the potential benefits. The rate of return is identified as the highest discount rate by which benefits exceed costs.

In order to minimize the effects on the SSTOP optimization algorithm, the economic analysis option was coded primarily as a separate subroutine (ENCMC).

Column	Format	Entry
1-5	I5	7 (Card Type)
6-10	F5.0	BASE CONDITION DELAY (tcu-hrs/hr.) - the total network delay calculated by SSTOP for the traffic network without the improvement under consideration.
11-15	F5.0	BASE CONDITION STOPS (stops/hr.) - the total network stops calculated by SSTOP for the base traffic network. Although these delays and stop values are not used in the economic analysis, their inclusion can help the user in identifying other potential benefits associated with a network improvement (eg. a reduction in stops can reduce the number of rear-end collisions)

Column	Format	Entry
16-20	F5.0	BASE CONDITION EXCESS FUEL CONSUMPTION (L/hr.) - the total network fuel consumed due to signal caused acceleration/decleration and idling for the base condition.
25	I1	ECONOMIC ANALYSIS TYPE - two alternatives are available to the user: 1 = rate of return 2 = net present worth
26-30	F5.0	EQUIVALENT ANNUAL FACTOR - the SSTOP optimization is generally carried out for a representative hour of traffic conditions. The fuel consumption reduction for one hour is multiplied by the equivalent annual factor to produce a yearly estimate of fuel reduction under the proposed improvement. The value of this factor must be determined by the user based on his perception of the number of hours per year where similar benefits can be obtained.
31-35	I5	PROJECT LIFE (years) - the number of years in which fuel consumption benefits will be obtained.
36-40	F5.0	DISCOUNT RATE (%) - this value is only required when the net present worth method is selected by the user.
41-45	F5.0	IMPROVEMENT COST ($) - the present value cost of the network improvement.
46-50	F5.0	PRICE OF FUEL ($/L, $/gal.) - the cost per unit fuel consumed is input either in terms of litres or gallons, depending on the type of units selected by user in Card Type 2.

3.10 CARD 99999 - END OF DATA CARD

Card 99999 has 9's entered in the first five columns. This card is required to signify the end of data and is therefore the last card in the data deck in optimization runs.

3.11 CARD TYPE 6 - EVALUATOR CARD

To employ the program as an evaluator it is necessary to provide a data deck structured identically to that required for optimization with the following modifications and additions.

1. An entry of 'YES' or 'Y' is made in columns 56-60 of card type 2 indicating that an evaluation run is desired.

2. The one cycle length to be evaluated is entered in both the minimum and maximum system trial cycle length fields on card type 2 (columns 6-10 and 16-20 respectively). A non-zero cycle length increment is also required to maintain programming logic.

   Only one cycle length may be evaluated per run since it is necessary to specify intersection offset numbers in seconds. These offset numbers are peculiar to each cycle length and cannot be generalized.

   In evaluation runs, the card type 5 must always be included, even if default values are desired.

3. The 99999 card following the card types 3, 4 and 5 is still included in the data deck. Following this is the set of card type 6 which specify the network timing characteristics to be evaluated. This card type is discussed in the following section.

4. Following the card types 6 is a second end of data card. However instead of 99999 in columns 1-5 an entry of 88888 is made.

There is one card type 6 entered for each intersection in the network. Input requirements are discussed below, and illustrated in Figure 3.7. All entries are right-justified. Example coding is taken from Appendix A, for intersection number 520.

> NOTE: One Card Type 6 card is required (in the current version of SSTOP) to start the Evaluation routine. This card should be blank except for the 6 in column 5. This card is then followed by the Card Type 6 for each node 5.

Column	Format	Entry
1-4	I4	Count Column - these columns are provided to allow the user to number the input data cards to assist in structuring the data deck. SSTOP does not read these columns.
5	I1	6 (card type).
6-10	I5	Intersection Number - the number of the intersection for which timing parameters are contained on this card.

ENTRY	COUNT COLUMN	C* T	INTERSECTION NUMBER	LENGTH OF FIRST GREEN INTERVAL	LENGTH OF SECOND GREEN INTERVAL	LENGTH OF THIRD GREEN INTERVAL	LENGTH OF FOURTH GREEN INTERVAL	LENGTH OF FIFTH GREEN INTERVAL	LENGTH OF SIXTH GREEN INTERVAL	OFFSET NUMBER					
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	70	75	80
FORMAT	A4	11	15	15	15	15	15	15	15	15					
EXAMPLE CODING	6	6	630	30	5	53	0	0	0	69					

Figure 3.7/ Card Type 6-Evaluator Card

Column	Format	Entry
11-15	I5	Length of First Green Interval (seconds) - the order of this and subsequent green intervals input on this card must conform with the phase sequence employed on card types 3 of the links associated with this intersection. This entry consists of the duration of the first green interval only and does not include any clearance time. The clearance times are assumed to be those entered on card type 2 or card type 3, whichever has precedence.
16-20		
21-25		
26-30		
31-35		
36-40	I5	AS for above but for second, third fourth, fifth and sixth green intervals respectively. Note - The entries made in columns 11-40 are interval specific. Thus any split-phase will have two consecutive entries. For an advanced green split-phase, the duration of the flashing green is entered first, followed by the duration of the solid green. For delayed green split-phases, the solid green duration is entered first, then the flashing green duration. The sum of the green intervals plus the clearance times from card types 3 should be equal to the cycle length.
41-45	I5	Offset Number - the time, in seconds, at which the first green interval of the intersection being considered is activated with respect to the first green interval of a given reference intersection. This intersection offset number is not to be confused with link offsets. The offset numbers required here are identical to those values provided on SSTOP output (see Section 4.2).

Note - In the evaluation process SSTOP calculates minimum and desirable cycle lengths for each intersection. Should the system cycle length being evaluated prove insufficient to meet the cycle length requirements of any given signal(s), this signal is kicked out and assumed to operated at its desirable cycle length. Green times are in the same proportion as those input on card type 6. This procedure is necessary to ensure that identical evaluation techniques are used by both the evaluator and the optimizer.

If the sum of the green times and clearance times for an intersection is less than or greater than the system cycle length, the green times will be scaled proportionally to the values input on card type 6 so

that the sum of green times and clearance times does equal the cycle length, subject to the condition that this intersection can operate at the system cycle length. If it cannot, scaling still proceeds but the desirable cycle length, as calculated by SSTOP is employed instead of the system cycle length.

3.12 CARD TYPE 88888 - END OF DATA - EVALUATOR

Card 88888 has 8's entered in the first five columns and signifies end of data for evaluation runs, and is thus the last card in the data deck.

3.13 Card Type 10 - Time Space Diagram Parameters

The addition of subroutine PLOTTS to the SSTOP program now enables output data to be transformed into a time-space diagram format. In this format, time is plotted horizontally while the distance between links is plotted vertically. This is an option and if not desired requires no additional coding requirements.

If desired, the additional coding effort is minimal, being limited to an additional variable on card type 5 (see Section 3.8) and the addition of card types ten and eleven.

There must be one card type ten for each time space diagram and there is no limit to the number of diagrams per cycle length. If time-space diagrams are requested, a card type ten card is required for each diagram per cycle length and for each cycle length examined, otherwise the program fails due to a system error. For example, if 2 diagrams are requested per cycle length and 4 cycle lengths are examined (60-70-80-90) then 8 card type 10's are required.

Column	Format	Entry
1-5	I5	10 (card type)
6-10	I5	LNUMTS - number of links to be plotted on current time-space diagram; no limit.
11-15	I5	SHTS - horizontal scale for time-space diagrams (seconds per inch) - default = 40.
16-20	I5	SVTS - vertical scale (feet or metres per inch) - default = 400 feet or 120 metres.
21-80	30A2	TITTS - any user defined alphanumeric title for current diagram.

The accuracy of the time-space diagrams are highly dependent on the two scales to be used for time and distance.

The horzontal scale defaults to 40 seconds per inch (or four seconds per character) and the vertical scale defaults to either four hundred feet per inch (fifty feet per line) or one hundred and twenty metres per inch (fifteen metres per line). All these scales can be overriden by the user on card type ten, and can be varied from one diagram to the next. Although there is no limit placed on either scale, only one hundred and twenty characters will be plotted on the time scale.

The accuracy of the time per interval plotted is:
$\pm$ (time scale per inch $\div$ 10)

The accuracy of the distance plotted is:
$\pm$ (vertical scale per inch $\div$ 10)

The accuracy of the total cycle lengths plotted for non-kicked out intersections or links (ie. intersections using the network cycle length) is:

$\pm$ (time scale per inch $\div$ 10)

Intersections that have been kicked out and are running at non-network cycle lengths will be plotted at the network cycle length. The user should be cautioned that these links may appear to be co-ordinated on the time space diagram when in fact they are not.

Being limited to plotting only an integer number of characters, and due to the rounding procedure used, a correction factor is required to ensure that the cycle lengths plotted for the network cycle lengths and are consistant among the links to allow for progression bandwidths to be observed. All links will have their cycle length adjusted to the network cycle length. This correction consists of either adding or subtracting an appropriate number of characters to or from the largest interval plotted. The largest interval was chosen to minimize the percentage charge to that interval.

3.14 Card Type 11 - Time Space Diagrams Link Cards

The purpose of this card is to provide the program with a list of the links which are desired for each time-space diagram. There must be at least one card type 11 for each diagram to be output. The number of card type elevens is dependent on the number of links to be printed. There is no maximum number of links but only sixteen can be placed on each card type eleven.

For phases that include either an advanced or delayed green interval, it is recommended that the advanced or delayed green link be plotted even if it is the through link that is to be examined. This will ensure that the full through green period (which includes the flashing green time) is plotted.

The symbols plotted represent advanced, delayed or neutral green intervals, red intervals, clearance intervals and the offset derived from the program used to coordinate the plotted diagram.

Column	Format	Entry
1	A1	SIGN(I): Blank for neutral green interval, + for delayed green interval, - for advanced green interval
2-5	I4	NMETS(I): Link number to be output on diagram.
	(A1,I4)	repeat above for each link of diagram up to 16 per card type 11, no limit on number of card type elevens which may be included.

3.15 SUMMARY OF INPUT DATA REQUIREMENTS AND DATA DECK STRUCTURE

While details of the input data requirements and data deck structure are contained in previous sections of this chapter, multi-time users who are familiar with program operation will find this synopsis very useful since it provides a complete description of input requirements. First-time users or those wishing to refamiliarize themselves with the program should study the more detailed explanation in the sections which preceed this summary.

Complete input data requirements and formats, including examples, are illustrated in Figure 3.8. The coding of geometric features and their impact on the tcu conversion process are outlined in Table 3.1. To assist in structuring the data deck, Table 3.2 provides an explanation of the card type requirements, including the limiting values on any input parameter. Figure 3.9 depicts a properly structured data deck.

ENTRY	CARD TYPE	USER IDENTIFIABLE TITLE	NOT USED
CARD COLUMN	5	10 15 20 25 30 35 40 45 50 55 60 65 70 75	80
FORMAT	I5	70A1	
EXAMPLE CODING	1	ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK	

(a) - Card Type 1 (Title Card)

ENTRY	CARD TYPE	MINIMUM CYCLE LENGTH	CYCLE LENGTH INCREMENT	MAXIMUM CYCLE LENGTH	MAXIMUM KICKOUT LENGTH	NUMBER OF LINKS	NUMBER OF INT'NS	NETWORK STOP PENALTY	NETWORK CLEARANCE INTERVAL	METRIC UNITS?	DATA CHECK?	NOT USED
CARD COLUMN	5	10	15	20	25	30	35	40	45	50	55	60 65 70 75 80
FORMAT	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5	A5	
EXAMPLE CODING	2	60	10	80	120	96	28	4	4		YES	

(b) Card Type 2 (Network Parameters Card)

ENTRY	COUNT COLUMN	C*T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL	
CARD COLUMN	4	5	10	15 20	25	30	35	40	45 50 55 60 65 70 75 80
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5	
EXAMPLE CODING	3	3	1001	WLLNDOS	2	1400	11		

(c) Card Type 3 (Link Information Card)

ENTRY	COUNT COLUMN	C*T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A6	I5	I5	I5	I5	I5	I5	I5	I5	I5	A6
EXAMPLE CODING	4	4	1001	0	0	0	LEFT	69	186	77	1						

(d) Card Type 4 (Approach Card)

ENTRY	CARD TYPE	LEFT TURN TCU	RIGHT TURN TCU	TRUCK AND BUS TCU	VEHICLES CLEARED IN AMBER	PLATOON DISPERSION FACTOR	NOT USED
CARD COLUMN	5	10	15	20	25	30	35 40 45 50 55 60 65 70 75 80
FORMAT	I5	F5.0	F5.0	F5.0	I5	F5.0	
EXAMPLE CODING	5	1.80	1.35	2.1	80	.50	

(e) Card Type 5 (Optional User Parameters Card)

*CARD TYPE

Figure 3.8/ Summary of Data Input Requirements for Optimization

Table 3.1 - Geometric Features Summary

FEATURE	SPECIFICATION	IMPACT
'T' intersection	T	Left and right turn tcu set to 1.0
Left and right-turn bays or lanes capable of storing all turning vehicles	BOTH or B	Left and right turn tcu set to 1.0
Left-turn bay or lane capable of storing all left-turning vehicles	LEFT or L	Left turn tcu set to 1.0
Right-turn bay or lane capable of storing all right-turning vehicles	RIGHT or R	Right turn tcu set to 1.0
One way street with no turning bays or lanes	ONE	Left turn tcu set equal to right turn tcu

Table 3.2 - Data Card Requirements And Structure

CARD NAME AND TYPE	NUMBER OF CARDS IN DATA DECK	PLACEMENT IN DATA DECK	COMMENTS AND PARAMETER LIMITS
Title Card (Card Type 1)	One	First Card	Up to 70 spaces to allow user to input a test run title which is printed at the top of each page of output
Network Parameters Card (Card Type 2)	One	Second Card	Min Cycle Length $\geq$ 40sec. Cycle Length Increment $\geq$2sec. Max System Cycle Length $\leq$ 120sec. Number of Trial Cycle Lengths $\leq$ 10 Number of links = # of card Type 3 $\leq$ program dimension $\leq$ 300 Number of intersections $\leq$ program dimension $\leq$ 60
Link Information Card Type 3)	One for each link (internal and external) in the network	Card types 3 for all links of an approach immediately preceed the approach card type 4 in in the data deck. Non-neutral card 3 preceeds neutral card type 3. Parallel link with direction code less than or equal to four preceeds parallel link with direction code greater than four.	All link and approach data for any intersection must appear as group-total number of green intervals for any intersection 6 Link direction code 8
Approach Card (Card Type 4)	One for each neutral link in the network	As above	Sum of volumes in the columns 31-45 >0. Any entry in columns 61-80 requires specification of all source links

Table 3.2 - Data Card Requirements And Structure (Cont'd)

CARD NAME AND TYPE	NUMBER OF CARDS IN DATA DECK	PLACEMENT IN DATA DECK	COMMENTS AND PARAMETER LIMITS
User specified Parameters (Card Type 5)	One (optional)	Following last card type 4	
User Specified Parameters for Economic analysis of potential fuel benefits (Card Type 7)	One (optional)	Following Card type 5	Included on this card is information concerning the base network performance values & the various economic parameters.
99999	One	Last card in Optimization run.	Signifies end of data for optimization
Evaluator Card (Card Type 6)	One for each intersection plus one blank card type 6 to start Evaluation routine.	Following 99999 card	For evaluation runs only
88888	One	Last card in Evaluation run.	
(Card Type 10)	One for each diagram	Following end of data deck card 99999 or 88888	Title and horizontal and vertical scales for time-space diagrams
(Card Type 11)	At least one for each Card Type 10	Following Card type 10	List of links for each diagram.

Figure 3.9 – Data Deck Structure

4. OUTPUT

Before proceeding with any extensive calculation or providing any output, SSTOP undertakes some minor checking of input data. Should a program-identified error exist, an error message will be printed indicating the source of the error, followed by program termination. A list of these error messages is found in Appendix E. The data check is by no means exhaustive and it is possible for the program to terminate on a machine-flagged error. If no errors are encountered, then the seven major sections of output is printed.

The first consists of a reorganized version of the input data (Figures 4.1-4.5. Data contained on Figure 4.5 is printed only during evaluation runs.) Included in this section are listings of any default values or assumed information, such as source link identification. Second, there is a section of output which contains the group of cycle length calculations and selected cycle lengths for each intersection (Figure 4.6). These first two sections are printed only once. For each trial cycle length there is a table listing link performance characteristics (Figure 4.7) and a table containing the final signal timing for that trial cycle length (Figure 4.8). Finally, a table identifying system performance levels for each trial cycle length is provided (Figure 4.9).

Figures 4.1-4.4 and 4.6-4.9 provide sample output obtained from a run using the network illustrated in Appendix A. Data contained on Figure 4.5 was obtained using the optimum splits and offset numbers from the 80 second optimization run for the example network of Appendix A. The output for this optimization run is listed in Figure A.17 of Appendix A. Contained on the output are numbered references. These numbers may be used as indices to the following pages to provide detailed explanation as to the source of the output and how it should be used. References to other sections of the text are also made.

In addition to these section, it is also possible that one or more non-fatal messages may be printed. To allow for possible remote batching jobs and to provide scratch paper for hand calculations, output has been limited to a 72-column field.

4.1 OUTPUT DESCRIPTION

1. USER IDENTIFIABLE TITLE - Obtained from Card Type 1 - See Section 3.1.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- (1)

INPUT DATA-NETWORK PARAMETERS ---------- (2)
****

MINIMUM SYSTEM TRIAL CYCLE LENGTH = 50 SECONDS ---------- (a)

CYCLE LENGTH INCREMENT = 10 SECONDS ---------- (b)

MAXIMUM SYSTEM TRIAL CYCLE LENGTH = 80 SECONDS ---------- (c)

MAXIMUM KIKOUT SIGNAL CYCLE LENGTH = 120 SECONDS ---------- (d)

NUMBER OF LINKS IN NETWORK = 96 ---------- (e)

NUMBER OF INTERSECTIONS = 28 ---------- (f)

NETWORK STOP PENALTY = 4 SEC/STOP --------- (g)

NETWORK CLEARANCE INTERVAL = 4 SECONDS---------- (h)

DEFAULT TO IMPERIAL UNITS ---------- (i)

OPTIMIZATION RUN. FULL OUTPUT FOR EACH TRIAL CYCLE ------- (j)

**OPTIONAL CARD 5 HAS NOT BEEN INCLUDED
THE FOLLOWING VALUES ARE ASSUMED ---------- (3)

LEFT TURN TCU = 1.750 ---------- (a)

RIGHT TURN TCU = 1.250 ---------- (b)

TRUCK AND BUS PCU = 2.000 ---------- (c)

LEFT TURN VEHICLES CLEARED IN AMBER = 100 PER HOUR ---- (d)

PLATOON DISPERSION FACTOR = .25 ---------- (e)

Figure 4.1 - Typical Output - Card Types 2 and 5

2. INPUT DATA-NETWORK PARAMETERS - Program generated headings. Indicates data contained on card type 2 follows. See Section 3.2. Printed once each run.

   a. columns 6-10, card type 2. The program will assume a minimum cycle length of 40 seconds if the value entered here is less than 40.

   b. columns 11-15, card type 2. The program will assume a 10 second cycle length increment if the value entered here is less than one.

   c. columns 16-20, card type 2. The program will not process any system cycle lengths greater than 120 seconds, nor will it process more than 10 cycle lengths. The program internally sets this parameter so neither of these two constraints are violated.

   d. columns 21-25, card type 2.

   e. columns 26-30, card type 2.

   f. columns 31-35, card type 2.

   g. columns 36-40, card type 2.

   h. columns 41-45, card type 2.

   i. columns 46-50, card type 2. Blank or zero - DEFAULT TO IMPERIAL UNITS. 'YES" or 'Y' - METRIC UNITS SPECIFIED.

   j. columns 56-60, card type 2. Blank or zero - OPTIMIZATION RUN. FULL OUTPUT FOR EACH TRIAL CYCLE. 'YES' or 'Y' - EVALUATION RUN. If entry in columns 51-55 'YES' or 'Y' then also - DATA CHECK REQUESTED.

3. List of key program parameters. See Section 3.8. Printed once each run.
   Card 5 not included:
   ** OPTIONAL CARD 5 HAS NOT BEEN INCLUDED
   THE FOLLOWING VALUES ARE ASSUMED
   or if Card 5 included then
   ** OPTIONAL CARD 5 HAS BEEN INCLUDED
   THE FOLLOWING VALUES WILL BE USED

   a. from Card 5, columns 6-10 or default of 1.75 - not less than 1.0

   b. from Card 5, columns 11-15 or default of 1.25 - not less than 1.0

   c. from Card 5, columns 16-20 or default of 2.00 - not less than 1.0

   d. from Card 5, columns 21-25 or default of 100

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- ①

INPUT DATA-PHASE INFORMATION ---------- ④
****

ⓐ INT'N NO.	ⓑ LINK NO.	ⓒ LINK NAME	ⓓ PHASE NO.	ⓔ SATURATION FLOW (TCU/GRN-HR)	ⓕ MINIMUM GREEN (SEC)	ⓖ CLEARANCE INTERVAL (SEC)
300	3001	CHURCHQS	2	1250	14	4
	3002	QUEENCW	1	1300	13	4
	3003	CHURCHQN	2	1250	14	4
	3004	QUEENCE	1	1300	13	4
310	3101	CHURCHJS	2	1350	17	4
	3102	JAMESCW	1	1650	17	4
	3103	CHURCHJN	2	1350	17	4
	3104	JAMESCE	1	1200	17	4
320	3201	KINGQS	2	1200	16	4
	3202	QUEENKW	1	2750	15	4
	3203	KINGQN	2	1200	16	4
330	3301	KINGJS	2	1350	18	4
	3302	JAMESKW	1	2750	16	4
	3303	KINGJN	2	1800	18	4
340	3401	PAULQS	2	1200	15	4
	3404	QUEENPE	1	2550	16	4
350	3501	PAULJS	2	1150	18	4
	3504	JAMESPE	1	2550	13	4
400	4002	CRLILKW	1	2460	17	4
	4003	KINGCN	2	1280	12	4
410	4101	KINGAS	2	950	14	4
	4102	ACDMYKW	1	2760	12	4
	4103	KINGAN	2	1000	14	4
420	4201	COURTKS	2	1175	14	4
	4202	KINGCW	1	2685	14	4
	4203	COURTKN	2	1100	14	4
430	4301	PAULCS	2	1100	18	4
	4303	PAULCN	2	1850	18	4
	4304	CRLILPE	1	2550	17	4

Figure 4.2 - Typical Output - Phase Information

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- ①

INPUT DATA-LINK CHARACTERISTICS ---------- ⑤
****

ⓐ INT'N NO.	ⓑ LINK NO.	ⓒ LINK NAME	ⓓ UPSTREAM INT'N	ⓔ LENGTH (FEET)	ⓕ DESIGN SPEED (MPH)	ⓖ GEOMETRIC FEATURES	ⓗ LINK IMPORTANCE MULTIPLIER
510	5101	CHRCHNS	610	1340	21	RIGHT	10
	5102	NIGRACW	-	-	-	ONE	10
	5103	CHRCHNN	520	860	21	LEFT	10
520	-5201	ADV PAULGS					
	5201	PAULGS	500	620	12	-	10
	5203	PAULGN	530	800	13	-	10
	5204	R GNVAPE	440	890	20	-	10
	5208	TL GNVAPE	440	890	20	LEFT	10
530	5301	RACEGS	520	800	23	-	10
	5302	GNVAGW	-	-	-	-	10
	5303	GALEGN	-	-	-	-	10
	5304	GNVARE	-	-	-	-	10
600	6001	WLLNDGS	-	-	-	LEFT	10
	6002	GNVAWW	610	1180	18	BOTH	10
	6003	WLLNDGN	500	760	21	LEFT	10
	6004	GNVAWE	130	2070	31	LEFT	10
610	6101	WLLNDNS	620	1190	22	-	10
	6102	NIGRAWW	-	-	-	LEFT	10
	6103	WLLNDNN	510	1340	22	-	10
	-6104	ADVNIGRAWE					
	6104	NIGRAWE	600	1180	20	LEFT	10
620	6201	RUSSLNS	630	1100	24	-	10
	6203	RUSSLNN	610	1190	27	-	10
	6204	NIGRARE	-	-	-	T	10
630	-6301	ADVSSERVNS					
	6301	SSERVNS	640	430	23	LEFT	10
	6303	SSERVNN	620	1100	28	-	10
	6304	NIGRASE	-	-	-	T	10
640	6401	NSERVNS	-	-	-	-	10
	6402	NIGRANW	-	-	-	T	10
	+6403	DELNSERVNN					
	6405	NSERVNN	630	430	27	LEFT	10

Figure 4.3 - Typical Output - Link Characteristics

e. from Card 5, columns 26-30 or default of 0.25

4. INPUT DATA-PHASE INFORMATION - program generated heading. Indicates data contained on type 3 cards to be listed. See Section 3.6. Printed once each run.

   a. INT'N NO. - obtained by dropping direction code from link number (see Section 3.3).

   b. LINK NO. - card 3, columns 6-10

   c. LINK NAME - card 3, columns 11-20

   d. PHASE NO. - card 3, columns 21-25

   e. SATURATION FLOW (TCU/GRN-HR) - card 3 columns 26-30. Units of tcu/grn-hr assumed when printing heading, but other units may apply (see Section 3.5).

   f. MINIMUM GREEN (SEC) - card 3, columns 31-35

   g. CLEARANCE INTERVAL (SEC) - set using following conventions.

      if card 3, column 36-40 greater than zero, clearance interval = entry in these columns
      if card 3, columns 36-40 equal to zero and link
         negative then clearance interval = 0
         neutral with no delayed green or link is positive then clearance interval = clearance interval specified on card type 2, columns 41-45.

5. INPUT DATA-LINK CHARACTERISTICS - program generated heading indicating link information from card type 4 to be printed. See Section 3.7. Printed once for each run.

   a. INT'N NO. - obtained from link numbers

   b. LINK NO. - card 3, columns 6-10

   c. LINK NAME - card 3, columns 11-20

   d. UPSTREAM INT'N - card type 4, columns 11-15. Negative or positive links are paired with their corresponding neutral link. External links have no upstream intersection - indicated by dash.

   e. LINK LENGTH (FEET) - if card type 2, columns 46-50 blank or zero
      (METRES) - if card type 2, columns 46-50 'YES' or 'Y'
      value obtained from card 4, columns 16-20. Negative or positive links are paired with their corresponding neutral link. External links have no link length - indicated by dash.

   f. DESIGN SPEED (MPH) - if card type 2, columns 46-50 blank or zero
      (KM/H) - if card type 2, columns 46-50 'YES' or 'Y'
      value obtained from card 4, columns 21-25. Priority links are paired with corresponding neutral link. External links have no design speed.

g. GEOMETRIC FEATURES - card type 4, columns 26-30

h. LINK IMPORTANCE MULTIPLIER - card 4, columns 51-55. Default value is 10. The multiplier is divided by 10 before being used (See Section 3.7).

6. INPUT DATA-TRAFFIC CHARACTERISTICS - program generated heading indicating traffic data from card 4 follows. See Section 3.7. Printed once for each run. Priority left-turn volumes taken from card 4, columns 31-35. Link number not included due to desire to keep output within 72-column field.

a. INT'N NO. - derived from link name

b. LINK NAME - card 3, columns 11-20

c. LINK EXIT VOLUMES (VPH) - obtained from card 4 columns 31-45. Vehicles per hour assumed but other units may apply (See Section 3.5).

d. PERCENT TRUCKS BUSES - obtained from card 4, columns 46-50

e. SOURCE LINKS - obtained from card 4 columns 56-80 or program-generated as described in Sections 3.3 and 3.7. The program automatically identifies negative or positive source links. Under the 4th SOURCE heading the LINK indicates the link number from which flow enters the upstream end of the link being considered, while the MOVE indicates which movement provides the contributing flow. If any entries at all (except for zero's) are made in columns 56-80, all source links must be completely specified. See Section 3.7 for further clarification.

7. INPUT DATA - EVALUATION RUN FOR 80 SECOND CYCLE - program generated heading indicating evaluation run for a given cycle length (in this case 80 seconds) has been requested. This section printed only when entry on card type 2 columns 56-60 is 'YES' or 'Y'.

a. INT'N NO. - intersection specified on card type 6 columns 6-10.

b. GREEN INTERVAL LENGTHS (SECONDS) - entries specified on card type 6 columns 11-40. A split phase will have two green interval entries.

c. OFFSET NUMBER - from card type 6, columns 41-45.

8. CYCLE LENGTH CALCULATIONS - program generated heading indicating program calculated signal cycle lengths to be printed. See Section 2.2 and Section C.2.2 Printed once each run.

If a message has been printed here indicating that a particular intersection is oversaturated, see Section E.1.16.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- ①

INPUT DATA-TRAFFIC CHARACTERISTICS ---------- ⑤
****

ⓐ INT'N NO.	ⓑ LINK NAME	ⓒ LINK EXIT VOLUMES (VPH)			ⓓ PERCNT TRUCKS BUSES	ⓔ SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
510	CHRCHNS	0	0	739	3	6102	6101	6104	-	-
	NIGRACW	0	390	41	2	-	-	-	-	-
	CHRCHNN	10	370	0	2	-5201	5208	5203	-	-
520	ADV PAULGS	125	0	0	1	5002	5001	-	-	-
	PAULGS	0	584	0	1	5002	5001	-	-	-
	PAULGN	25	323	159	2	5304	5303	5302	-	-
	R GNVAPE	0	260	45	3	4401	4404	-	-	-
	TL GNVAPE	101	174	0	3	4401	4404	-	-	-
530	RACEGS	8	625	0	2	-	-	5304	-	-
	GNVAGW	31	39	21	0	-	-	-	-	-
	GALEGN	129	628	79	1	-	-	-	-	-
	GNVARE	23	36	35	1	-	-	-	-	-
600	WLLNDNS	19	449	10	2	-	-	-	-	-
	GNVAWW	58	318	3	2	6103	6102	6101	-	-
	WLLNDGN	56	249	31	2	-	5003	5002	-	-
	GNVAWE	32	218	88	1	1301	1304	1303	-	-
610	WLLNDNS	53	553	82	1	-	6201	6204	-	-
	NIGRAWW	123	267	67	1	-	-	-	-	-
	WLLNDNN	18	278	78	1	-	5103	5102	-	-
	ADVNIGRAWE	55	0	0	1	6001	6004	6003	-	-
	NIGRAER	0	266	15	1	6001	6004	6003	-	-
620	RUSSLNS	0	444	30	1	-	6301	6304	-	-
	RUSSLNN	16	433	0	2	-6104	6103	6102	-	-
	NIGRARE	45	0	17	1	-	-	-	-	-
630	ADVSSERVNS	97	0	0	1	6402	6401	-	-	-
	SSERVNS	0	373	0	1	6402	6401	-	-	-
	SSERVNN	0	409	10	1	6204	6203	-	-	-
	NIGRASE	11	0	8	1	-	-	-	-	-
640	NSERVNS	0	446	108	1	-	-	-	-	-
	NIGRANW	65	0	32	1	-	-	-	-	-
	DELNSERVNN	22	0	0	1	6304	6303	-	-	-
	NSERVNN	0	456	0	1	6304	6303	-	-	-

Figure 4.4 - Typical Output - Traffic Characteristics

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ---------- ①

INPUT DATA-EVALUATION RUN FOR 80 SECOND CYCLE --------- ⑦

****

INT'N NO.	GREEN INTERVAL LENGTHS (SECONDS)						OFFSET NUMBER
	1	2	3	4	5	6	
100	37	35	0	0	0	0	14
110	14	58	0	0	0	0	20
120	47	33	28	0	0	0	0
130	45	27	0	0	0	0	74
200	16	56	0	0	0	0	62
210	34	38	0	0	0	0	68
220	45	27	0	0	0	0	58
230	38	34	0	0	0	0	7
300	50	22	0	0	0	0	79
310	42	30	0	0	0	0	74
320	49	23	0	0	0	0	38
330	40	32	0	0	0	0	30
340	40	32	0	0	0	0	61
350	36	36	0	0	0	0	66
400	44	28	0	0	0	0	29
410	44	28	0	0	0	0	27
420	43	29	0	0	0	0	15
430	54	18	0	0	0	0	1
440	56	18	0	0	0	0	0
500	54	9	45	0	0	0	0
510	25	47	0	0	0	0	34
520	26	5	37	0	0	0	0
530	20	52	0	0	0	0	0
600	26	46	0	0	0	0	30
610	5	31	32	0	0	0	62
620	17	55	0	0	0	0	36
630	30	5	53	0	0	0	69
640	25	37	6	0	0	0	0

Figure 4.5 - Typical Output - Evaluator Input Data

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- ①

CYCLE LENGTH CALCULATIONS ---------- ⑧
****

ⓐ INT'N NO.	ⓑ SELECTED CYCLE LENGTHS		ⓒ CALCULATED CYCLE LENGTHS				
	DESIRABLE CYCLE (SEC)	MINIMUM CYCLE (SEC)	MINIMUM CYCLE (SEC)	WEBSTER 0.9*cap (SEC)	WEBSTER 1.0*cap (SEC)	MIN GREEN 0.9*cap (SEC)	MIN GREEN 1.0*cap (SEC)
100	60	60	31	21	18	29	27
110	60	60	22	17	15	46	41
120	120	90	79	139	68	102	85
130	60	60	44	15	14	36	34
200	60	60	41	36	27	55	48
210	60	60	42	17	16	35	34
220	60	60	38	16	14	36	35
230	60	60	46	25	21	44	41
300	60	60	35	15	14	33	32
310	60	60	42	21	18	39	37
320	60	60	39	16	15	36	35
330	60	60	42	21	18	40	38
340	60	60	39	20	17	34	33
350	60	60	39	22	19	38	36
400	60	60	37	18	16	30	28
410	60	60	34	16	15	32	30
420	60	60	36	16	15	32	30
430	60	60	43	20	18	48	44
440	60	60	36	14	13	37	35
500	120	120	47	295	295	60	60
510	60	60	50	18	16	51	48
520	90	80	73	84	70	81	76
530	60	60	43	16	14	45	43
600	60	60	52	27	22	53	49
610	60	60	57	29	23	48	45
620	60	60	41	11	11	32	31
630	70	70	64	11	11	53	51
640	60	60	58	20	19	54	52

Figure 4.6 - Cycle Length Calculations

a. INT'N NO. - derived from link number.

b. SELECTED CYCLE LENGTHS

1) DESIRABLE CYCLE (SEC) - the cycle length at which the signal should operate, allowing for a 10% margin in capacity. This value is the maximum of the WEBSTER 0.9 x CAP calculation and the MIN. GREEN 0.9 x CAP calculation.

2) MINIMUM CYCLE (SEC) - the minimum cycle length at which the signal remains undersaturated without violating the minimum green requirements specified on type 3 cards, columns 31-35. This value will be the maximum of the MINIMUM CYCLE (under the heading CALCULATED CYCLE LENGTHS) the WEBSTER 1.0 x CAP calculation.

Neither of these values will be less than the minimum system trial cycle length specified on card type 2 columns 6-10 nor greater than the maximum kicked out signal cycle length specified on card type 2, columns 21-25.

Additionally, the selected cycle lengths are both rounded to the next highest value of CMIN + INT x INCR where CMIN is the minimum trial cycle length specified on card type 2, columns 6-10, INT is an integer, and INCR is the trial cycle length increment from card type 2, columns 11-15, subject to the constraints previously mentioned.

c. CALCULATED CYCLE LENGTHS

1) MINIMUM CYCLE (SEC) - the total of the minimum green and clearance interval durations for all phases in the cycle.

2) WEBSTER 0.9 * CAP - cycle length based on Webster's Method, assuming 90% utilization of the signal capacity.

3) WEBSTER 1.0 * CAP - cycle length based on Webster's Method, assuming 100% utilization of the signal capacity.

4) MIN. GREEN 0.9 * CAP - cycle length dependent on V/S ratios and minimum green durations, assuming 90% utilization of signal capacity.

5) MIN. GREEN 1.0 * CAP - cycle length dependent on V/S ratios and minimum green durations, assuming 100% utilization of signal capacity.

9. System trial cycle length

10. LINK PERFORMANCE - program generated heading indicating performance characteristics of links to be printed. Printed once for each system trial cycle length.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- (1)

NETWORK CYCLE LENGTH = 80 SECONDS ------------------ (9)

LINK PERFORMANCE ----------(10)
****

(a) INT'N NO.	(b) LINK NO.	(c) LINK NAME	(d) V/S RATIO	(e) DEG. OF SAT.	(f) DELAY (TCU-HRS/HR) UNIFRM	(f) DELAY (TCU-HRS/HR) RANDM	(g) TCU STOPS PER HOUR	(h) TRAVEL TIME (TCU-HRS/HR)	(i) AVG SPEED (MPH)
430	4301	PAULCS	.134	.596	.38	.22	121	1.3	10.0
	4303	PAULCN	.085	.378	1.03	.10	133	-	-
	4304	CRLILPE	.408	.604	1.00	.20	430	5.7	16.6
440	4401	PAULAS	.064	.320	.58	.04	74	1.1	8.6
	4404	ACDMYPE	.315	.450	.46	.09	113	3.1	18.1
500	5001	CHRCHGS	.404	1.054	6.38	8.12	1074	22.0	4.1
	5002	GNVACW	.488	1.046	10.82	8.12	1785	24.2	4.1
	-5003 ADV	CHRCHGN	.197	2.364	1.06	3.65	214	5.4	3.6
	5003	CHRCHGN	.346	.741	2.03	.96	264	4.3	8.4
510	5101	CHRCHNS	.330	.550	.53	.07	141	9.5	19.7
	5102	NIGRACW	.172	.573	2.65	.35	378	-	-
	5103	CHRCHNN	.237	.395	.28	.06	78	2.8	18.4
520	-5201 ADV	PAULGS	.157	2.512	.27	.24	41	1.7	8.5
	5201	PAULGS	.368	.920	3.25	4.76	857	13.8	5.0
	5203	PAULGN	.215	.637	2.38	.32	479	8.6	8.9
	5204 R	GNVAPE	.232	.928	1.68	2.73	300	7.0	7.4
	5208 TL	GNVAPE	.202	.808	1.41	.84	250	4.6	10.1
530	5301	RACEGS	.232	.357	.15	.05	150	4.4	21.9
	5302	GNVAGW	.091	.364	.73	.09	97	-	-
	5303	GALEGN	.343	.528	1.79	.27	511	-	-
	5304	GNVARE	.092	.368	.74	.10	98	-	-
600	6001	WLLNDGS	.407	.708	1.49	.77	350	-	-
	6002	GNVAWW	.193	.594	1.32	.22	287	6.2	13.6
	6003	WLLNDGN	.233	.405	.82	.12	193	3.3	14.9
	6004	GNVAWE	.227	.698	1.52	.39	296	6.2	21.4
610	6101	WLLNDNS	.314	.739	2.56	.53	616	10.1	15.3
	6102	NIGRAWW	.318	.771	2.41	1.17	441	-	-
	6103	WLLNDNN	.293	.389	1.16	.38	319	5.9	16.2
	-6104 ADV	NIGRAWE	.068	1.088	.14	.06	17	.8	15.1
	6104	NIGRAWE	.318	.669	.30	.33	195	3.8	16.7

Figure 4.7 - Link Performance Indicators

a. INT'N NO. - derived from link number

b. LINK NO. - from card type 3, columns 6-10

c. LINK NAME - from card type 3, columns 11-20

d. V/S RATIO - volume to saturation flow ratio where volume and saturation flow are in the same units. Generally, the volume figures contained on card type 4, columns 31-45 are converted to tcu vehicles using the tcu and pcu conversion factors specified (see 3, above) subject to geometric features (see Section 3.7).

The left-turn volumes from card type 4, columns 31-35 are used in calculating the V/S ratio for priority left-turn links while the corresponding neutral link employs only the volumes in columns 36-45 on card type 4. No tcu conversions are applied to left-turn priority green flows.

e. DEG. of SAT. - Degree of saturation

$$X = \frac{V/S}{G/C}$$

where X = degree of saturation
V/S = volume to saturation flow ratio
G = green period for that link
C = cycle length.

The ratio of the green time required to service all vehicles to the green time provided. Thus a degree of saturation equal to 1.0 indicates that the entire green period provided to that link is required to service vehicular demand. Due to random fluctuations in demand however, a degree of saturation greater than 0.9 should be considered critical.

In the case of priority left-turn links, the degree of saturation will always exceed 1.0 since the V/S ratio employed in this calculation does not discount for those vehicles cleared in the clearance interval. The degree of saturation, once these vehicles have been accounted for, should be less than 1.0.

A degree of saturation greater than 1.0 for all links of an intersection indicates that the maximum kickout cycle length specified on card type 2, columns 21-25 was not high enough to provide the required amount of green time to service vehicular demand. Either the signal should be operated at a higher cycle length, the clearance times shortened, or the capacity of the intersection should be increased. For such signals the delay and stop values will be vastly underestimated as SSTOP does not contain techniques for dealing with over-saturated signals.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- (1)

****
* *
* CALCULATED *
* SIGNAL TIMINGS * ---------- (11)
* *
* CY = 80 SEC *
****

(a) INT'N NO.	(b) CYCLE LENGTH (SEC)	(c) OFFSET SEC(PERCNT)	(d) PHASE NO.	(e) LINK NO.	(f) LINK NAME	(g) GREEN TIME SEC(PERCNT)	(h) CLEARANCE INTERVAL SEC(PERCNT)
530	80	*** ***	1	5302	GNVAGW	20(25)	4(5)
				5304	GNVARE		
			2	5301	RACEGS	52(65)	4(5)
				5303	GALEGN		
600	80	30(37)	1	6002	GNVAWW	26(32)	4(5)
				6004	GNVAWE		
			2	6001	WLLNOGS	46(56)	4(5)
				6003	WLLNOGM		
610	80	62(77)	1	-6204	ADVNIGRAWE	5(6)	4(5)
				6102	NIGRAWW	31(39)	4(5)
				6104	NIGRAWE		
			2	6101	WLLNONS	32(40)	4(5)
				6103	WLLNONN		
620	80	36(45)	1	6204	NIGRARE	17(21)	4(5)
			2	6201	RUSSLNS	55(69)	4(5)
				6203	RUSSLNN		
630	80	69(86)	1	6304	NIGRASE	30(37)	4(5)
			2	-6301	ADVSSERVNS	5(6)	4(5)
				6301	SSERVNS	33(40)	4(5)
				6303	SSERVNN		
640	80	0(0)	1	6402	NIGRANW	25(31)	4(5)
			2	6401	NSERVNS	37(45)	4(5)
				6403	NSERVNN		
				+6403	DELNSERVNN	6(7)	4(5)

Figure 4.8 - Calculated Signal Timings

f. DELAY (TCU-HRS/HR)

1) UNIFRM

- uniform delay
- for neutral, internal links for non-kicked out signals, see Section C.3.2
- for non-neutral, external links or links having dischange controlled by a kicked out signal, see Section C.3.1.

2) RANDM

- random delay
- for neutral, internal links for non-kicked out signals, see Section C.3.2.
- for non-neutral, external links or links radiating from or flowing into a kicked out signal, see Section C.3.1

These delay values are relative indicators only. They are not necessarily estimators of actual on-street performance.

g. TCU STOPS PER HOURS

- the number of vehicles per hour which make a complete stop on that link
- for neutral, internal links for non-kicked out signals, see Section C.3.2
- for non-neutral, external links or links radiating from or flowing into a kicked out signal, see Section C.3.1

The number of stops is a relative indicator only. It is not necessarily a measure of actual on-street performance.

h. TRAVEL TIME (TCU-HRS/HR) - calculated for all but external links

$$TT = \frac{L}{DS \times K} \times V + D_U + D_R$$

where
TT = total link travel time in veh-hrs/hr
L = link length in feet (or meters) from card type 4, columns 16-20
DS = Design speed in mph (or kph) from card type 4, columns 21-25. L and DS for internal, non-neutral links are assumed to be equal to those of the corresponding neutral

link.
K = 5280 if imperial units, 1000 if metric units.
V = total tcu volume on link. For priority left-turn movements the volume employed is that on the following Card Type 4, columns 31-35. Only the pcu conversion factor is applied to this volume; the left turn tcu factor being set to 1.0 for the left-turn link.
D_U = uniform delay on link in veh-hrs/hr
D_R = random delay on link in veh-hrs/hr

External links have no travel time. The travel time values are relative indicators only and not necessarily a measure of on-street performance.

i. AVG SPEED (MPH) or (KPH) - average speed in appropriate units

$$AS = \frac{L \times V}{TT \times K}$$

where AS = average speed in mph (or kph)
L,V,TT,K - as defined above.

Since the average uniform and random delay per vehicle is not the same for the non-neutral link and its corresponding neutral link, the two links will not have the same average speed. Similarly for parallel links.

The average speed is a relative indicator of network performance and not necessarily a measure of on-street performance.

11. CALCULATED SIGNAL TIMINGS - for each trial cycle length, CY, the program prints the optimum offset numbers for each intersection, and the optimum green times for each link.

a. INT'N NO. - derived from link number

b. CYCLE LENGTH - selected cycle length. A cycle length different from the system cycle length, CY, indicates that the signal has been kicked out.

c. OFFSET NO. - the time at which the first green period of this intersection commences with respect to the time at which the first green period of the last intersection in the list commences.

The time is provided in both seconds and as a percentage of the system cycle length. Kicked out signals have no offset number. This is indicated by two sets of three asterisks each.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK ------- (1)

TOTAL SYSTEM PERFORMANCE VALUES ---------- (12)
****

(a)	(b)	(c)		(d)	(e)	(f)	(g)
TRIAL CYCLE LENGTH (SEC)	NO. OF KICKED OUT SIGNALS	TOTAL DELAY (TCU-HRS/HR)		TCU STOPS PER HOUR	PERF. INDEX	TOTAL INTRNL TRAVEL TIME (TCU-HRS/HR)	AVG. SYSTEM SPEED (MPH)
		UNIFORM	RANDOM				
60	9	126.1	69.6	26857	225.5	345.0	11.8
70	4	124.9	65.4	25250	218.3	338.5	12.1
80	4	130.9	62.5	24891	221.1	339.8	12.0

THE OPTIMUM CYCLE IS 70 SECONDS

Figure 4.9 - Total System Performance Values

d. PHASE NO. - from card type 3, columns 21-25

e. LINK NO. - from card types, columns 6-10

f. LINK NAME - from card type 3, columns 11-20. The link numbers and names are listed beside their appropriate phase number.

g. GREEN TIME - the amount of green time in seconds and as a percentage of the individual intersections cycle length, which is allotted to each phase and hence, to each link.

Any phase having an advanced or delayed green displayed within the phase will have two sets of entries in this section. The entries are interpreted as follows. For an advanced green indication the link having the advanced green is printed first for that phase. The green time printed consists of both the flashing portion of the green and of any solid green clearance. For the advanced green, a zero clearance interval, unless otherwise overridden, is printed. The solid green for the neutral links is then printed, as is the clearance time. Thus, the neutral link parallel to the negative link would have a green time equal to the sum of the two greens listed for that phase.

Extended (delayed) green signals have a slightly more complicated interpretation as follows. For the phase having the delayed green, the amount of green for the link opposing the delayed green link is printed. The clearance time printed applies to this link, but not to the opposing approach. Therefore, the link parallel to the delayed green link would have a green time equal to the green time printed plus the clearance interval plus the length of the delayed green. This would then be followed by a clearance interval equal in length to the second clearance time printed. These concepts are further discussed in the following section.

h. CLEARANCE INTERVAL - the duration in seconds and percentage of the individual signals cycle length, of the amber or amber plus all red period following each green period (see Section 3.7).

12. TOTAL SYSTEM PERFORMANCE VALUES - after all trial cycle lengths have been processed, a table of total system performance indicators is printed.

a. TRIAL CYCLE LENGTH (SEC) - the range of system trial cycle lengths specified on card type 2.

b. NO. OF KICKED OUT SIGNALS - the number of intersections within the network which cannot operate at the system trial cycle length plus the number of signals which have been kicked out because they are no longer joined with another signal which is to be co-ordinated. If all signals have been kicked out this value will be equal to the number of intersections in the network and all remaining performance indicators will be zero as this cycle length will not have been evaluated.

c. TOTAL DELAY (TCU-HRS/HR)

1) UNIFORM - total uniform network delay

$$UD_T = \sum_{i=1}^{n} D_u^i$$

where UD_T = total uniform delay

D_u^i = uniform delay for each link, i, in the network including neutral, non neutral and external.

2) RANDOM

- total random network delay
- calculation similar to UNIFORM

These values are relative indicators only. They are not necessarily a measure of on-street performance.

d. TCU STOPS PER HOUR - total number of stops in the network during the design period. Calculated as per UNIFORM delay. It is a relative measure only and not necessarily an indicator of on-street performance.

e. PERF. INDEX - total system performance. The lowest value here indicates the optimum trial cycle length.

$$PI = UD_T + RD_T + \frac{k \times S_T}{3600}$$

where PI = performance index
UD_T = total uniform delay in veh-hrs/hr
RD_T = total random delay in veh-hrs/hr
k = stop factor from card 2, columns 36-40, columns 36-40 in seconds/stop
S_T = total number of stops

f. TOTAL INTERNAL TRAVEL TIME (TCU-HRS/HR) - the total vehicle travel time within the network, including delay, for all but external links. This gives a measures of the performance of the links within the network itself.

$$ITT_T = \sum_{i=1}^{n} TT_i$$

where ITT_T = total internal travel time

TT = travel time for each link i in the network as previously defined under 8 (g)

g. AVG. SYSTEM SPEED - in mph or km/h - the average link and volume weighted speed of all links within the network.

$$\bar{S} = \frac{\sum_{i=1}^{n} \frac{L_i \times V_i}{K}}{ITT_T}$$

where $\bar{S}$ = average system speed

L_i = link length for each internal link i in feet or meters

V_i = volume on each internal link i

ITT_T = total internal travel time as defined above

K = 5280 if imperial units, 1000 if metric.

4.2 OUTPUT INTERPRETATION

To assist in the interpretation of the signal timing information, the series 600 intersections taken from the sample network discussed in Appendix A will be used as an illustration. The timing patterns generated for this subnetwork for an 80 second cycle are presented in Figure 4.8. These timings have been transferred onto a subnetwork diagram on a link basis as illustrated in Figure 4.10. The sequence of indications presented to each link over one cycle length and the duration of each indication are presented beside each link. Offset numbers for each intersection are indicated at the centre of each intersection while link offsets are located at the midpoint of each link. The timing sequence and the offsets are derived as follows.

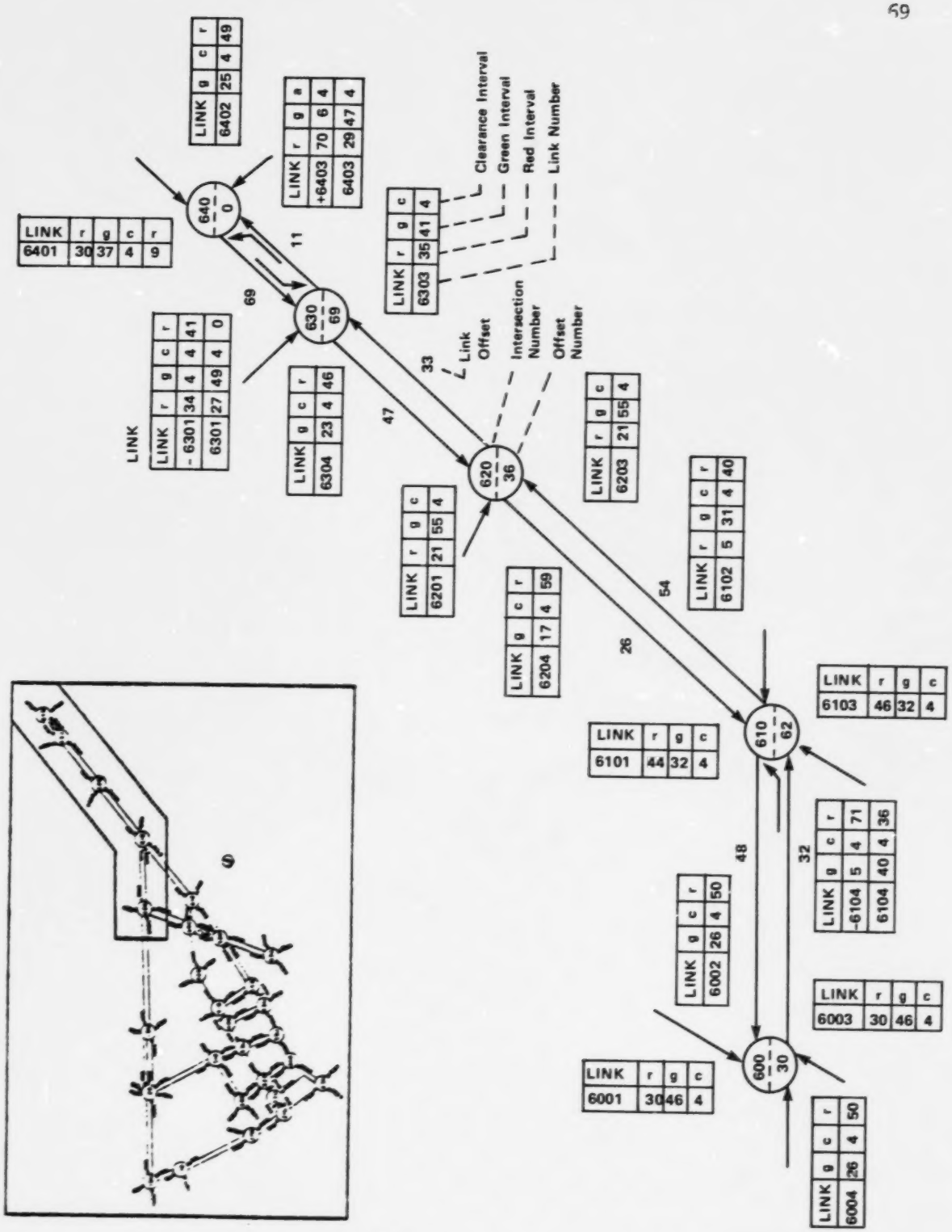


Figure 4.10 - Signal Timing for Series 600 Intersections

The offset number is first located with its corresponding intersection number. This offset number is the time at which the first green interval of the intersection being considered is activated with respect to the first green interval of the last intersection in the intersection list, and is not to be confused with the link offset. For example, the green interval for link -6104 of intersection 610 begins 62 seconds later than the first green interval of intersection 640.

Intersection 640 will be used to illustrate the proper assignment of green times and clearance intervals for an intersection having a delayed green indication. In the first phase only link 6402 is active; that is, has a green indication displayed to it. The green indication of 25 seconds is followed by a 4 second clearance interval. A red indication of 80-(25+4)=51 seconds follows. The second phase for intersection 640 is a split phase incorporating a delayed green indication for the northbound approach (links +6403, 6403). The timing for link 6401 with respect to the beginning of green for phase one would be 29 seconds of red during which the green and clearance intervals of phase one are displayed to link 6402; 37 seconds of green, a four second clearance interval and then 10 seconds of red during which the delayed flashing green and the clearance interval are displayed to links +6403, 6403. Timing for links +6403, 6403 would therefore be red = 29 seconds, green = 37+4+6=47 seconds (4 seconds to allow for clearance on link 6401, flashing green = 6 seconds), clearance interval = 4 seconds.

Analysis for an advanced green split phase is essentially similar. The key to properly calculating green times for each link is the following. Priority left-turn links and neutral links opposing this left-turn link are active only in the green interval designated. The neutral link(s) parallel to the priority left-turn are active in the interval designated, and during the priority green interval, and in the clearance interval separating these two intervals.

Links offsets may be calculated by using the offset numbers and the signal timings to determine the time difference between the start of two green indications controlling flow in the same direction. Reference to Figure 4.9 should indicate the proper procedure for determining these offsets.

In generating the offset numbers and timings, no attempt has been made to ensure that the offset number as presented would not result in an offset key being placed in an amber or all red location on the dial, or in a flashing green position. The user must check to ensure that this does not happen, and if necessary, adjust the offset numbers as required.

The optimum cycle length is that cycle length with the lowest performance index as calculated by SSTOP. However, this cycle is not necessarily the one which should be implemented. For example if the 80 second cycle has a performance index only slightly higher than that of the 70 second cycle, it may prove desirable to implement the 80 second cycle as this allows for more green time which can accommodate any cyclic traffic flow fluctuations. Also if a signal is kicked-out at the optimum cycle, it may prove desirable to move to a higher cycle length. The question to be asked is, "What would be the implications

if on-street demands, saturation flows, etc. are not as provided by input?" Sound engineering judgement can then prevail.

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APPENDIX A - SAMPLE NETWORK

To assist the user in network coding, a complete example is contained in this appendix. The network employed is a portion of the St. Catharines, Ontario signal system network. Figure A.1 indicates the location of St. Catherines in Southern Ontario, while a detailed illustration of the signal network is presented in Figure A.2. The schematic representation of the network is given in Figure A.3. The intersection numbering scheme consists of a series of three digit numbers which subdivide the network into sections. Thus all signalized intersections in section 2 of the network are identified by a number with a base of 200. This group of intersections is then termed the two hundred series of intersections.

Link numbering, where possible, conforms to the directional code outlined in Section 3.3. Briefly, southbound links consist of the intersection number followed by a one, westbound, the intersection number followed by a two, northbound, the intersection number followed by a three, and eastbound, the intersection number followed by a four. Advanced left-turn links are indicated by use of a negative sign preceding the link number of the through movement while a delayed left turn is indicated by a positive sign preceeding the link number. Welland Avenue was taken to be the major east-west arterial and in order to take full advantage of the source link coding convention it was not always possible to conform to the above practice. For example, Link 2002 is, in fact, a southbound link.

Section A.1 explains the coding contained on Card Type 1 and 2. Section A.2 - A.7 illustrate the Card Type 3 and 4 coding for each signal series within the network. In addition, these sections also contain detailed intersection diagrams and explanations of the coding process wherever deemed necessary. Contained within these sections are coding procedures for advanced and delayed greens, parallel links, pedestrian phases, five-legged intersections, triangular network configurations, and the use of geometric features coding.

For simplicity, all links having an odd-numbered direction code have been coded as being 'on' in the first phase, with even-numbered links being on in the second phase. In actual practice it would be beneficial to code the main street as having green during the first phase. The coding contained in the following sections do not illustrate the cards in the proper sequence. The numbering sequence in columns 1-4 of cards 3 and 4 indicate the correct order.

Figure A.1 - St. Catharines Location

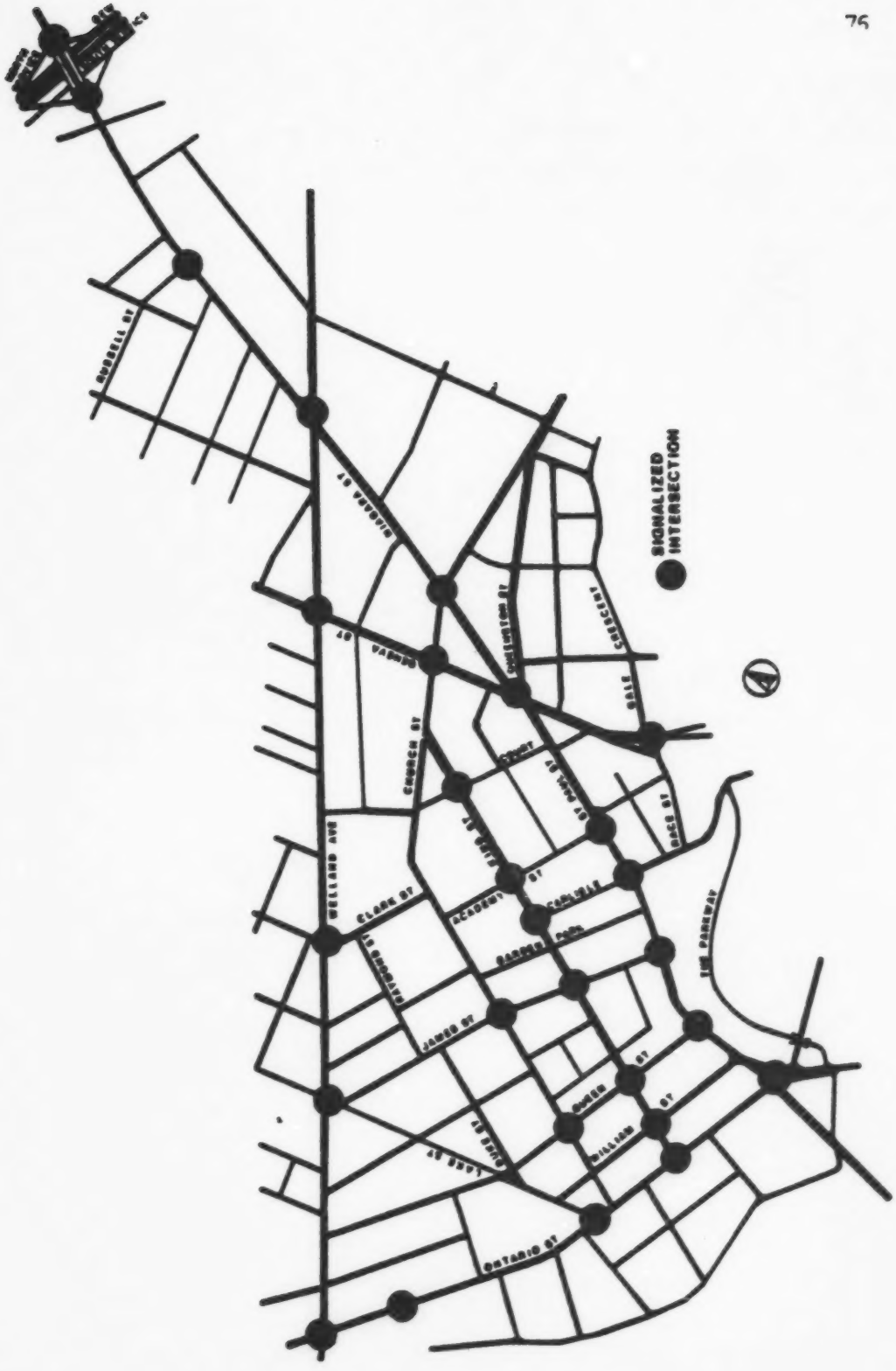

Figure A.2 - St. Catharines Network

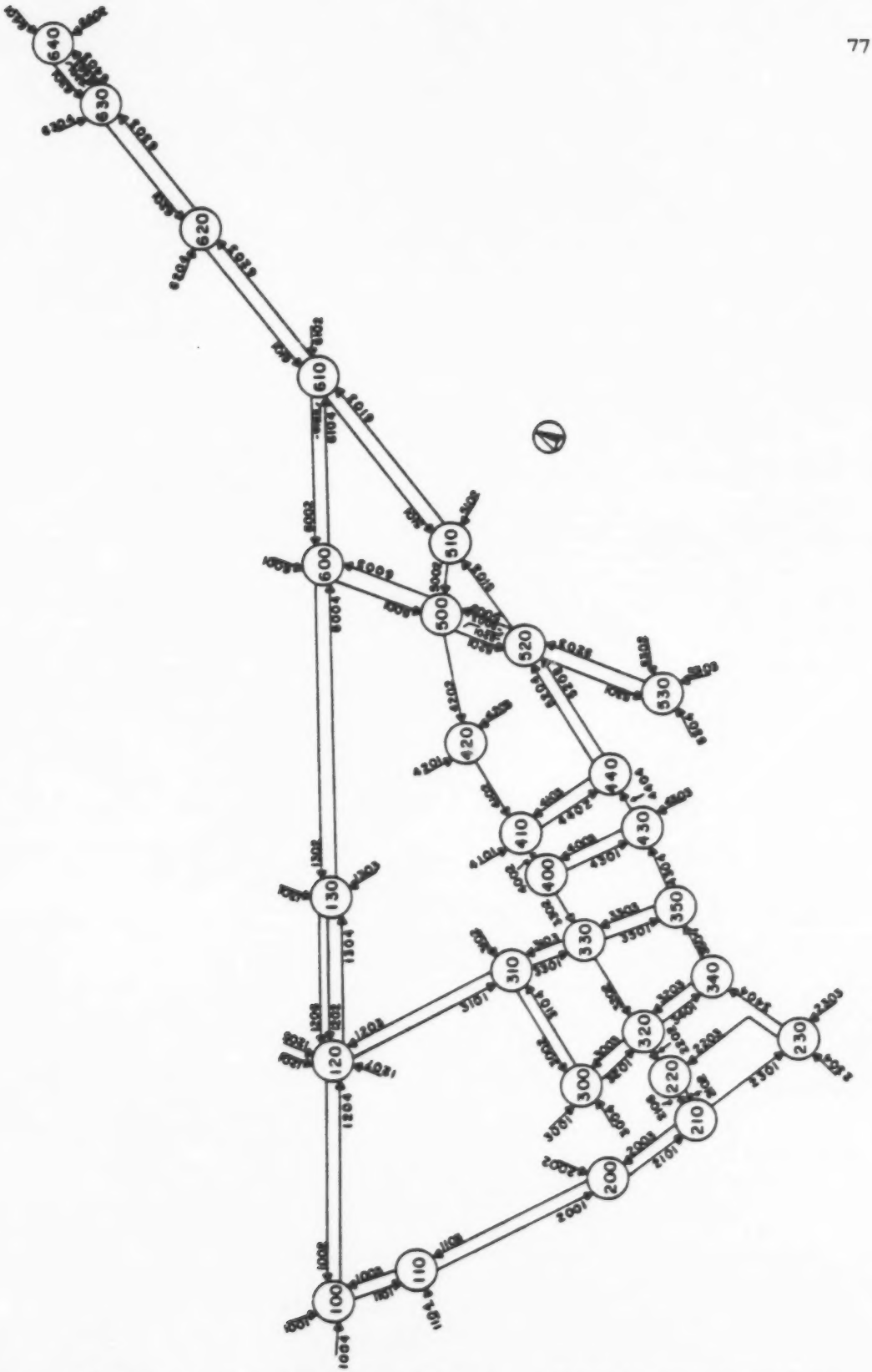

Figure A.3 - St. Catharines Network - Schematic Representation

ENTRY	CARD TYPE	USER IDENTIFIABLE TITLE														NOT USED
CARD COLUMN	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	I5	7 0 A 1														
	1	ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK														

Figure A.4(a) - Card Type 1

ENTRY	CARD TYPE	MINIMUM CYCLE LENGTH	CYCLE LENGTH INCREMENT	MAXIMUM CYCLE LENGTH	MAXIMUM KICKOUT LENGTH	NUMBER OF LINKS	NUMBER OF INT'NS	NETWORK STOP PENALTY	NETWORK CLEARANCE INTERVAL	METRIC UNITS?	DATA CHECK?	NOT USED				
CARD COLUMN	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5	A5					
EXAMPLE CODING	2	60	10	80	120	96	28	4	4		YES					

Figure A.4(b) - Card Type 2

Figure A.4 - Card Types 1 and 2 Coding

A.1 - CARD TYPES 1 and 2

Card Type 1 contains the user specified title. Since the network is being optimized for the A.M. peak period and is located in the St. Catherines Central Business District Area, the following title was used: 'St. Catharines Example Network - CBD - A.M. Peak'. Figure A.4(a) illustrates the coded Card Type 1.

Card Type 2 contains network parameters. For purposes of illustration, the desired system trial cycle lengths were 60, 70, and 80 seconds. Therefore the minimum trial cycle length (columns 6-10) is 60 seconds, the maximum cycle length (columns 16-20) is 80 seconds, while the cycle increment is 10 seconds (columns 11-15). The use of an even-valued minimum cycle length and cycle length increment permits all trial cycle lengths to be divided into two second increments without causing any rounding error. It is not expected that any signals will be oversaturated at 120 seconds. Therefore the maximum kickout cycle length (columns 21-25) is set to 120 seconds. The number of links and intersections in the network can be obtained from the schematic representation in Figure A.3. In this case there are 96 links (columns 26-30) and 29 intersections (columns 31-35). The network stop penalty is set at 4 seconds/stop, that is, each stop is considered equivalent to 4 seconds of delay (columns 36-40). For the St. Catharines network operation, most amber clearance intervals are equal to 3.8 seconds. As SSTOP can only accomodate integer values the clearance interval (columns 41-45) is set to 4. Design speed and link length will be in imperial units; thus columns 46-50 are left blank. It is desired to perform a data check on the integer fields in cards 3 and 4. A 'YES' is entered in columns 51-55 for this purpose.

The coded card type 2 is illustrated in Figure A.4(b).

A.2 - SERIES 100 INTERSECTIONS

The series 100 intersections are a group of four intersections located in the northeast corner of the network. Included in this grouping is a pedestrian actuated signal as well as a five-legged intersection. Figure A.5 provides a detailed illustration of the sub-network. Coding is shown in Figure A.6.

The pedestrian signal (number 110) is a actuated signal which provides pedestrian access to a hospital. Although the pedestrian phase will not be active every cycle, the worst possible situation was assumed; that is, an actuation every cycle. This ensures that upon actuation the pedestrian movement occurs during the least critical time in the cycle. Since an actuation does not in fact occur every cycle, actual on-street performance will be better than that indicated by SSTOP.

To simulate the pedestrian phase a 'dummy' traffic link 1104 was coded. As zero saturation flows and volumes are not permissible, these values are arbitrarily set so that the volume/saturation flow ratio will not result in a split which will give the pedestrian phase a green period longer than the 14 seconds required. The through volume was therefore set to 10 and the saturation flow to 1000. To ensure that the program does not attempt a simulation of traffic flow onto links 1003 or 2001 from link 1104, these two links are coded as

having source links 1103 and 1101 respectively, even though no turning movements were entered for link 1104.

It has also been assumed that the 14 second minimum green entered for link 1104 does not incorporate the flashing 'DON'T WALK' indication and hence the network clearance interval was allowed to apply. If a longer clearance time is desired, the value need merely be coded into columns 36-40. Alternatively, if the clearance time is included in the minimum green time, a zero clearance interval could be specified.

Links 1101 and 1103 have a zero minimum green value coded, since there are no parallel crosswalks. This ensures that the cycle length calculations for the signal are based solely upon capacity considerations and not upon any artificial minimum green requirements.

Intersection 120 is a five-legged intersection of which four approaches have four exit flows, the exception being James Street. As SSTOP provides for specification of only three exit volumes per link (left, through and right) it is necessary to simulate these approaches by use of two links, or by assuming that a particular movement is negligible, and hence, need not be coded. This latter assumption is made for the right-turn movement from Welland eastbound to Lake southbound which averages only 4 vehicles per hour, and for the right-turn movement from Lake northbound James southeast bound which is only 3 vehicles per hour. The assumption that these flows are zero does not significantly affect either the split or offset calculations as they represent less than 1% of the total flow on these approaches.

As none of the exit flows on two remaining approaches are negligible, it is necessary to represent these approaches by use of two links. The southbound Lake Street approach is represented by links 1201 and 1205, where link 1201 represents the section of roadway utilized by the through the right turn movement, and link 1205 the section of roadway used by the left turn movements. Link 1205 is coded as having an exclusive left-turn lane, thereby setting the left-turn tcu conversion factor to 1.0. The left turns to link 1304 are coded under the heading of number of left turns while the lefts to link 3101 are entered as through volume. This is totally permissible since both these movements will have a tcu conversion factor of 1.0. As this approach is external to the network no upstream intersection, design speed or link length values need be entered.

A similar convention is adopted for the westbound Welland approach. In this case however, links 1202 and 1206 are internal. They therefore have the same upstream intersection (indicating a parallel link), design speed and link length. Source codes for link 1206 need not be specified, provided its data cards follow those of link 1202 in the data deck.

The use of parallel links will result in two random delay calculations being performed for that approach. The user, during analysis of the data may elect to ignore one of these.

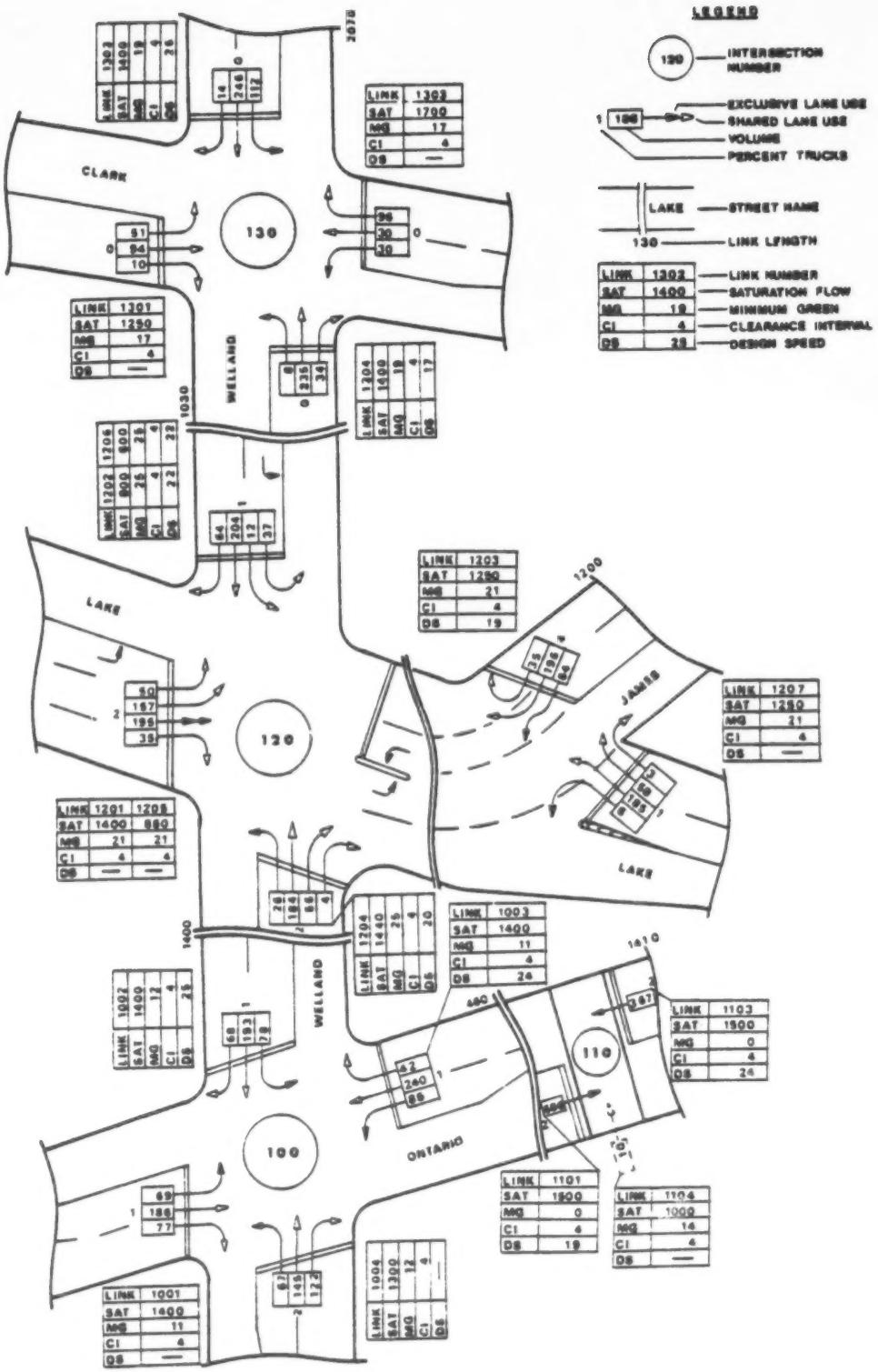

Figure A.5 - Series 100 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4 5		10	15 20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	3	3	1001	WLLNDOS	2	1400	11	
	5	3	1002	ONTWW	1	1400	12	
	7	3	1003	MLLNDOM	2	1400	11	
	9	3	1004	ONTME	1	1300	12	
	11	3	1101	PEDOS	2	1500	0	
	13	3	1103	PEDOW	2	1500	0	
	15	3	1104	ONTPED	1	1000	14	
	17	3	1201	RT WLLNDLS	2	1400	21	
	19	3	1205	L WLLNDLS	2	850	21	
	21	3	1202	RT LAKGMW	1	800	25	
	23	3	1206	L LAKGMW	1	600	25	
	25	3	1203	LAKGJN	2	1250	21	
	27	3	1207	JAHESLW	3	1250	21	
	29	3	1204	LAKEWW	1	1440	25	
	31	3	1301	WLLNDCS	2	1250	17	
	33	3	1302	CLARKWW	1	1400	19	
	35	3	1303	WLLNDCW	2	1700	17	
	37	3	1304	CLARKWE	1	1400	19	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A5	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5
	4	4	1001	0	0	0	LEFT	69	186	77	1						
	6	4	1002	120	1400	25	LEFT	78	193	68	1		1203	1202	1201	1207	LEFT
	8	4	1003	110	460	24	LEFT	85	240	42	1			1103			
	10	4	1004	0	0	0	LEFT	67	145	122	2						
	12	4	1101	100	460	19		0	686	0	2						
	14	4	1103	200	1410	24		0	367	0	2						
	16	4	1104	0	0	0		0	10	0	0						
	18	4	1201	0	0	0		0	195	35	2						
	20	4	1205	0	0	0	LEFT	50	157	0	2						
	22	4	1202	130	1030	22		0	204	64	1						
	24	4	1206	130	1030	22	LEFT	37	12	0	1						
	26	4	1208	310	1200	19	LEFT	64	196	35	4						
	28	4	1207	0	0	0	LEFT	6	185	58	1						
	30	4	1204	100	1400	20	LEFT	26	184	56	2						
	32	4	1301	0	0	0		51	94	10	0						
	34	4	1302	300	2070	25	LEFT	112	246	14	0						
	36	4	1303	0	0	0	LEFT	30	30	96	0						
	38	4	1304	120	1030	17		0	235	34	0		1205	1204	1203	1207	RIGHT

Figure A.6/ Series 100 Intersection Coding

As this intersection is non-standard due to its five-legged configuration, it is necessary to specify the source links for any links which have intersection 120 as its upstream intersection. In this case the affected links are 1002, 1204 and 3104.

Link 1002 will be used to illustrate the source link concept. Left turning vehicles from link 1203 enter the upstream end of link 1002. Thus 1203 is entered in the field labelled Left Turn Source Link on card type 4 for link 1002. A similar procedure is adopted for the through and right turns. As well as receiving the left turns from link 1203, link 1002 also receives the left-turning vehicles from link 1207. Thus, 1207 is entered as the fourth source link with LEFT being entered as the movement from the fourth source link.

A.3 SERIES 200 INTERSECTIONS

The four intersections comprising the series two hundred subnetwork are located in the southwest corner of the network. The subnetwork is illustrated in Figure A.7 with the coding contained in Figure A.8.

Intersection 210 is a 'T' intersection with the westbound approach forming the stem of the 'T'. As the left-turn movement is much greater than the right-turn movement, the use of an approach saturation flow would result in an underestimated V/S ratio for the left-turn movement and hence an under-designed green time. For this reason then, parallel links 2102 representing the roadway section utilized by left-turning vehicles and 2106, representing the roadway section for the right turns are used to represent this approach. Green time calculations will, therefore, be properly made. Coding for the two links follows the convention outlined in the series 100 discussion.

Although these links are a component of a one-way arterial, the entry of 'ONE' is not made in columns 26-30, rather 'T' is entered as it has greater priority in the tcu conversion process than does the 'ONE' specification (see Table 3.1). The 'ONE' specification is used however for link 2202, indicating the left-turn tcu conversion factor is set equal to the right-turn tcu conversion factor.

Link 2203 is coded as having intersection 230 as an upstream intersection. This is entered since left turns from St. Paul are made onto link 2203 not too far beyond the signal, and although not precise, it was felt that this more accurately represents network structure than listing link 2203 as external, which it would otherwise be.

A.4 SERIES 300 INTERSECTIONS

Six intersections form the 300 series subnetwork of signals. They are adjacent to and east of the series 200 intersections. Figure A.9 illustrates the subnetwork and Figure A.10 provides the coding. Since the five-legged intersection 120 is the upstream intersection for link 3101, it is necessary to specify the source links. Reference to Figures A.5 and A.6 will illustrate how these source links were determined.

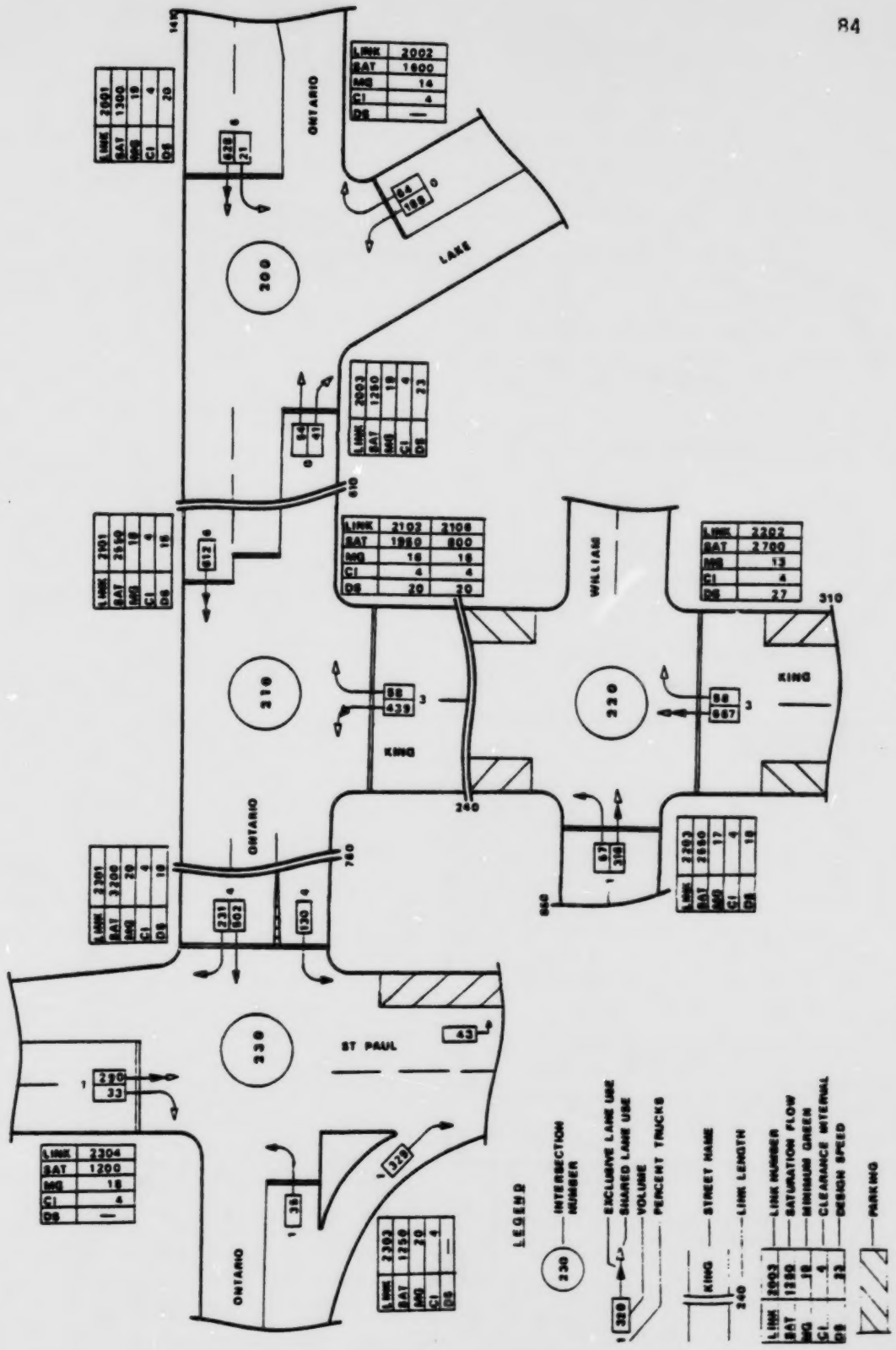

Figure A.7 - Series 200 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4 5	10	15	20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	39	3	2001	LAKEOS	2	1300	19	
	41	3	2002	OMTLW	1	1600	14	
	43	3	2003	LAKEOW	2	1250	19	
	45	3	2101	KINGOS	2	2550	16	
	47	3	2102	LEFT ONTEW	1	1950	16	
	49	3	2106	RIGHTONTEW	1	800	16	
	51	3	2202	WLLNKW	1	2700	13	
	53	3	2203	KINGNW	2	2550	17	
	55	3	2301	PAULOS	2	3250	20	
	57	3	2303	PAULOW	2	1250	20	
	59	3	2304	ONTPE	1	1200	18	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	
FORMAT	A4	I1	I5	I5	I5	I5	A5	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5
	40	4	2001	110	1410	20		21	628	0	6			1101			
	42	4	2002	0	0	0	T	188	0	64	0						
	44	4	2003	210	610	23		0	54	41	0				2106		
	46	4	2101	200	610	15	ONE	0	612	0	6						
	48	4	2102	220	240	20	T	439	0	0	3						
	50	4	2106	220	240	20	T	0	0	58	3						
	52	4	2202	320	310	27		0	667	58	3						
	54	4	2203	230	860	18		57	316	0	1						
	56	4	2301	210	760	18	BOTH	130	502	231	4						
	58	4	2303	0	0	0	T	35	0	329	1						
	60	4	2304	0	0	0	ONE	43	290	33	1						

Figure A.8/ Series 200 Intersection Coding

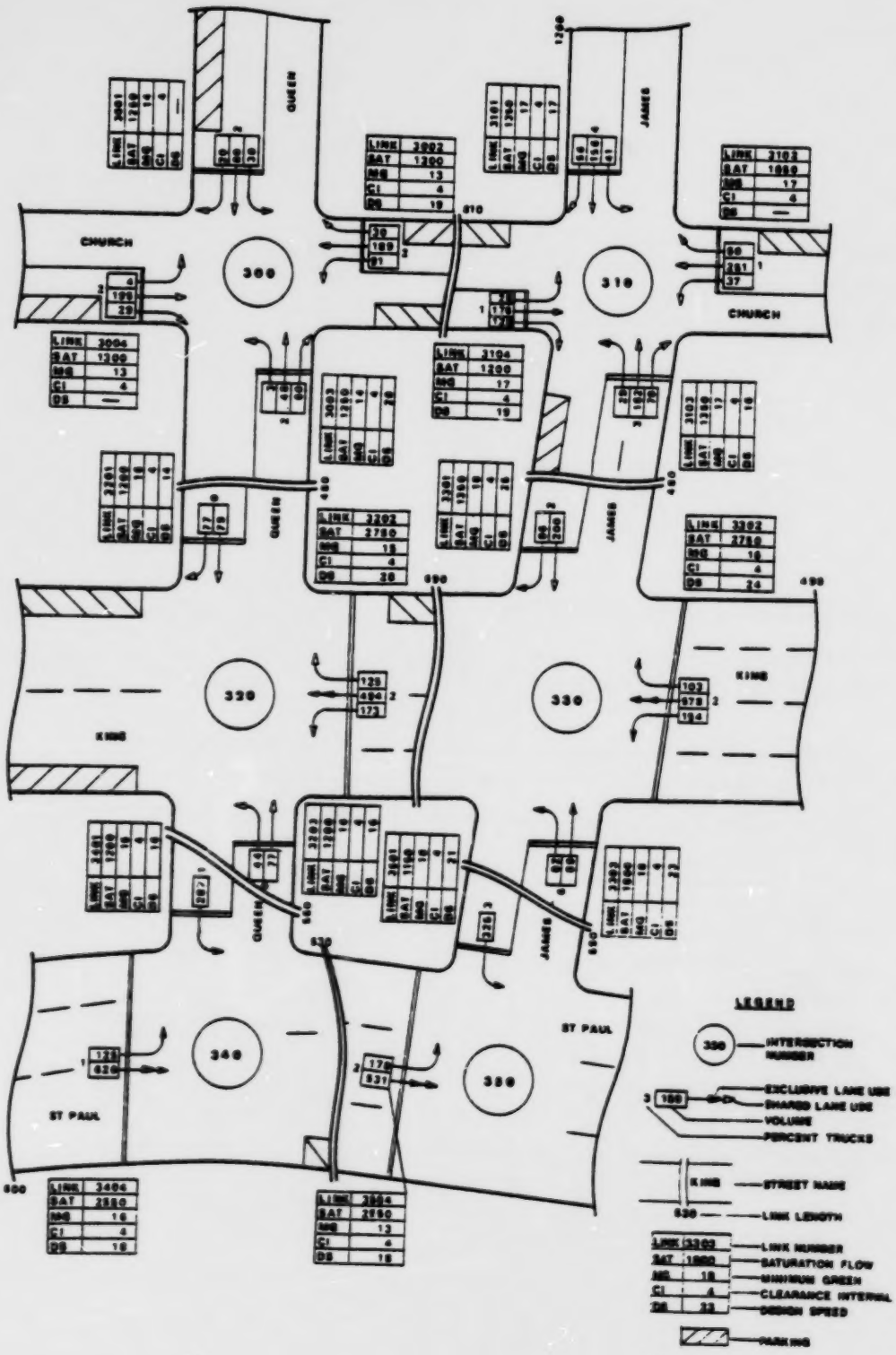

Figure A.9 - Series 300 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4	5	10	15 20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	61	3	3001	CHVRCHQS	2	1250	14	
	63	3	3002	QUEENCW	1	1300	13	
	65	3	3003	CHURCHQN	2	1250	14	
	61	3	3004	QUEENCE	1	1300	13	
	69	3	3101	CHURCHJS	2	1350	11	
	71	3	3102	JANESCW	1	1650	17	
	73	3	3103	CHURCNN	2	1350	17	
	75	3	3104	JANESCE	1	1200	16	
	77	3	3201	KINGQS	2	1200	16	
	79	3	3202	QUEENGW	1	2750	15	
	81	3	3203	KINGQN	2	1200	16	
	83	3	3301	KINGJS	2	1350	18	
	85	3	3302	JANESEW	1	2750	16	
	87	3	3303	KINGJN	2	1800	18	
	89	3	3401	PAULQS	2	1200	25	
	91	3	3404	QUEENPE	1	2550	16	
	93	3	3501	PAULJS	2	1150	18	
	95	3	3504	JANESPE	1	2550	13	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A5	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5
	62	4	3001	0	0	0		30	80	20	2						
	64	4	3002	310	810	19		91	189	30	3						
	65	4	3003	320	480	20		3	40	42	1						
	66	4	3004	0	0	0		4	195	29	2						
	70	4	3101	120	1200	17		41	156	56	4		1206	1205	1204		
	72	4	3102	0	0	0		37	251	60	1						
	74	4	3103	330	480	10	LEFT	29	162	70	3						
	76	4	3104	300	810	19		20	176	120	9						
	78	4	3201	300	480	14		0	79	77	0						
	80	4	3202	330	690	26	LEFT	173	494	125	2						
	82	4	3203	340	560	16		44	77	0	0						
	84	4	3301	310	480	25		0	200	96	2						
	86	4	3302	400	490	24	BOTH	154	578	103	2						
	86	4	3303	350	590	23	LEFT	82	89	0	6						
	90	4	3401	320	560	18	T	287	0	0	1						
	92	4	3404	230	600	18	LEFT	125	626	0	1						
	94	4	3501	330	590	21	T	325	0	0	3						
	94	4	3504	340	530	18	LEFT	176	531	0	2						

Figure A.10/ Series 300 Intersection Coding

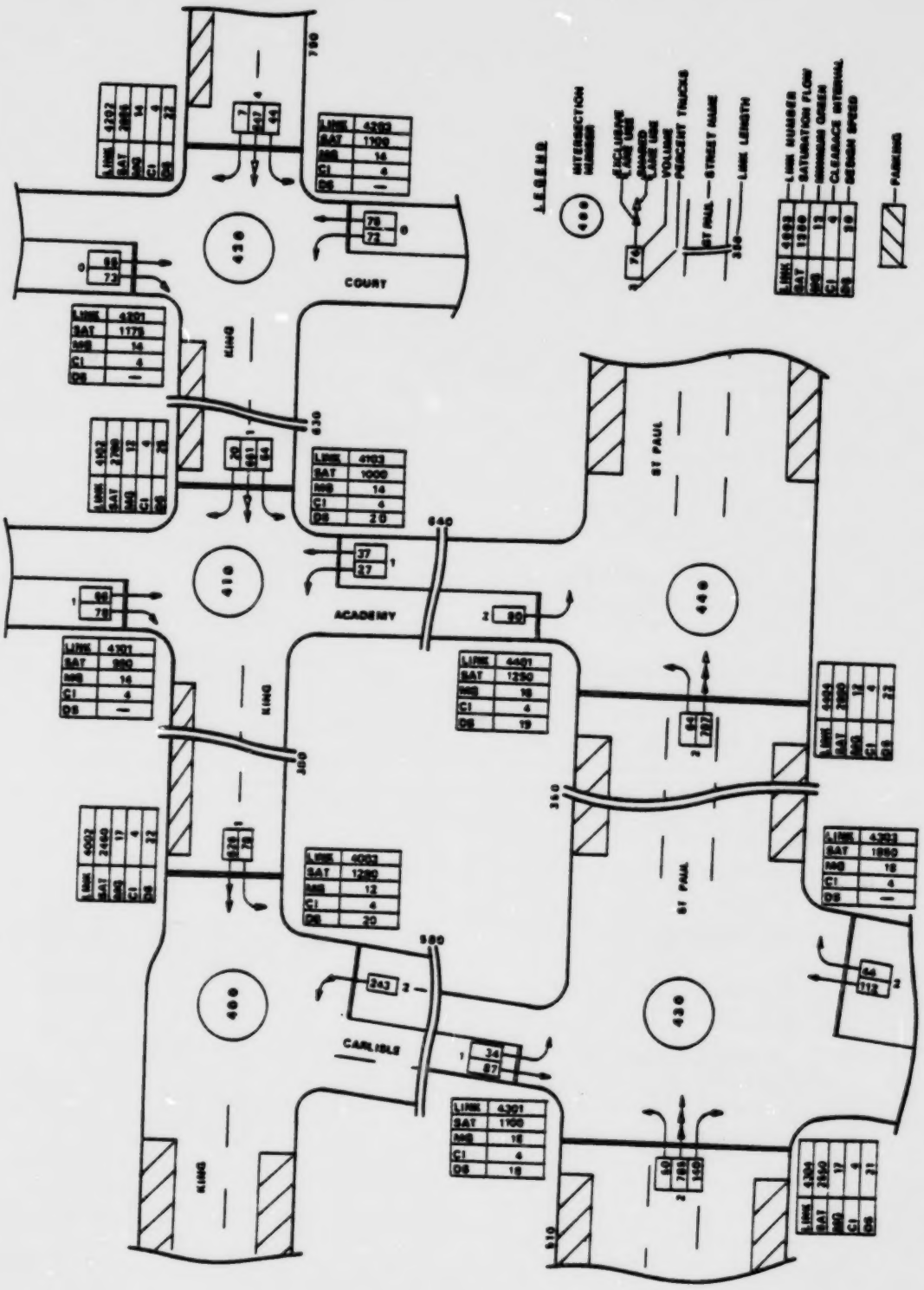

Figure A.11 - Series 400 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4	5	10	15 20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	97	3	4002	CHLILKW	1	2460	11	
	99	3	4003	KINGCN	2	1280	12	
	101	3	4101	KINGAS	2	950	14	
	103	3	4102	ACONYEW	1	2685	12	
	105	3	4103	KINGAN	2	1000	14	
	107	3	4201	COURTKS	2	1175	14	
	109	3	4202	KINGCW	1	2685	14	
	111	3	4203	COURTKN	2	1100	14	
	113	3	4301	PAULCS	2	1100	18	
	115	3	4303	PAULCN	2	1850	18	
	117	3	4304	CHLILPW	1	2550	17	
	119	3	4401	PAULAS	2	1250	16	
	121	3	4404	ACONYPE	1	2800	12	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A5	I5	I5	I5	I5	I5	I5	I5	I5	I5	A5
	98	4	4002	410	300	22	ONE	78	626	0	1						
	100	4	4003	430	580	20	T	243	0	0	2						
	102	4	4101	0	0	0		0	66	78	1						
	104	4	4102	420	630	25	ONE	54	661	20	1						
	106	4	4103	440	640	20		10	307	0	2						
	108	4	4201	0	0	0		0	65	73	0						
	110	4	4202	500	790	22	ONE	44	647	7	4						
	112	4	4203	0	0	0		72	75	0	0						
	114	4	4301	400	580	18		34	87	0	1						
	118	4	4303	0	0	0	RIGHT	1	112	44	2						
	118	4	4304	350	510	21	ONE	50	785	140	2						
	120	4	4401	410	640	19	T	80	0	0	2						
	122	4	4404	430	350	22	ONE	64	787	0	2						

Figure A.12/ Series 400 Intersection Coding

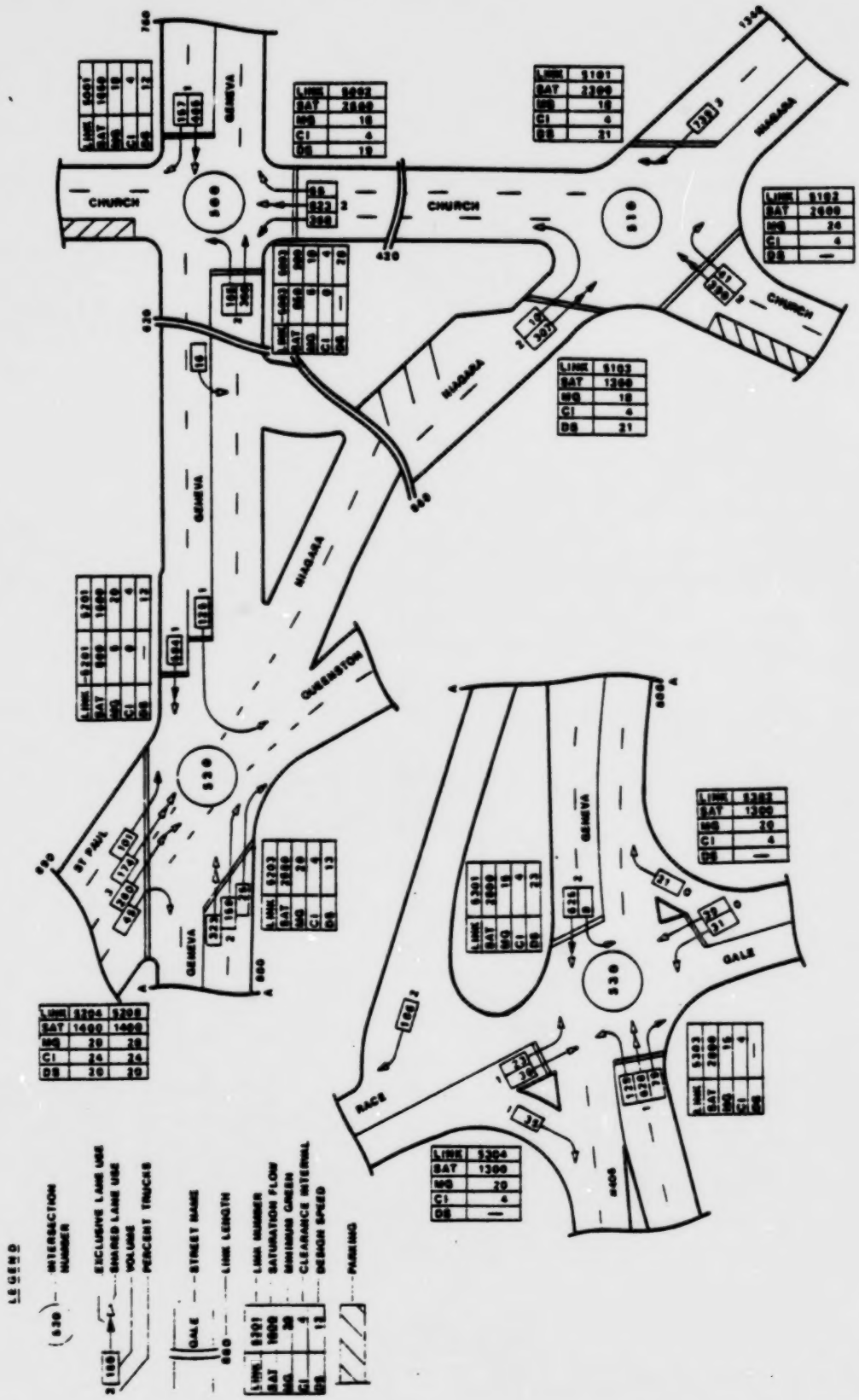

Figure A.13 - Series 500 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4	5	10	15 20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	123	3	5001	CHRCHGS	2	1650	18	
	125	3	5002	GMVACW	1	2660	16	
	127	3	-6003	ADVCHRCHGN	2	850	5	
	128	3	5003	CHRCHGN	2	900	18	
	130	3	5101	CHRCHNS	2	800	18	
	132	3	5102	NIGRACW	1	2600	24	
	134	3	5103	CHRCHNN	2	1360	18	
	136	3	-5201	ADV PAULGS	2	800	5	
	137	3	5201	PAULGS	2	1600	20	
	139	3	5203	PAULGN	2	2680	20	
	141	3	5204	R GNVAPE	1	1400	20	24
	143	3	5208	TL GNVAPE	1	1400	20	24
	145	3	5301	RACEGS	2	2800	15	
	147	3	5302	GNVAGW	1	1300	20	
	149	3	5303	GALEGN	2	2800	15	
	151	3	5304	GNVANE	1	1300	20	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A6	I5	I5	I5	I5	I5	I5	I5	I5	I5	A6
	124	4	5001	600	760	12		0	465	157	1						
	126	4	5002	510	420	19	LEFT	368	823	66	2						
	129	4	5003	520	620	28	LEFT	165	306	0	2		5208	5203			
	131	4	5101	610	1340	21	RIGHT	0	0	739	3						
	133	4	5102	0	0	0	ONE	0	390	41	2						
	135	4	5103	520	860	21	LEFT	10	307	0	2		5201	5208	5203		
	138	4	5201	500	620	12		125	584	0	1						
	140	4	5203	530	800	13		25	323	159	2						
	142	4	5204	440	890	20		0	260	45	3						
	144	4	5208	440	890	20	LEFT	101	174	0	3						
	146	4	5301	520	800	23		8	625	0	2						
	148	4	5302	0	0	0		31	39	21	0						
	150	4	5303	0	0	0		129	628	79	1						
	152	4	5304	0	0	0		23	36	35	1						

Figure A.14/ Series 500 Intersection Coding

A.5 SERIES 400 INTERSECTIONS

The five series 400 intersections located east of centre in the network contain no special examples. Figure A.11 depicts the subnetwork. Coding is contained in Figure A.12.

A.6 SERIES 500 INTERSECTIONS

Four intersections form the series 500 intersections. Located in the southeast corner of the network, they include a five-legged intersection with a pedestrian phase, advanced green indications and a triangular network configuration. Figure A.13 illustrates the network and Figure A.14 the coding.

Intersection 520 operates as a three phase intersection, one of which is used exclusively by pedestrians. Following the east-west green phase (phase 1), it is of 20-second duration. Therefore links 5204 and 5208 are coded as having a clearance interval of 24 seconds (20 seconds pedestrian phase plus 4 seconds for vehicle clearance). The pedestrian phase is manually activated and is therefore not active every cycle. Actual performance of this signal then would be better than that calculated by SSTOP. The decision to include the pedestrian phase as clearance time will have an impact on the cycle length calculations and may result in very high cycle length requirements. It may, in certain circumstances, prove more desirable to code the pedestrian phase as a separate phase as in the case of intersection 110.

Coding for links 5204 and 5208 follows the procedure outlined in Section A.2 for links 1202 and 1206 of intersection 120.

The northbound approach for intersection 500 and the southbound approach at intersection 520 have advanced flashing greens. To simulate this split-phase operation, a negative link with the same number as the parallel through and right turn link is coded on a card type 3. Even though the southbound approach at intersection 520 does not have an exclusive turn lane for left-turn vehicles, it is still necessary to explicitly calculate the left-turn saturation flow for this movement in order to determine the amount of green time required to adequately service the movement. the minimum green periods for these links are set to five seconds as they are not constrained by minimum pedestrian walk times. The minimum green period includes any solid green clearance interval. Within the data deck, the negative link card type 3 proceeds the neutral link card type 3 which is then followed by the neutral link card type 4.

Since intersections 500, 510 and 520 form a triangular configuration, it is not possible to code the links so that they conform to the standard network configuration. Therefore, it is necessary to provide the source link information for link 5103.

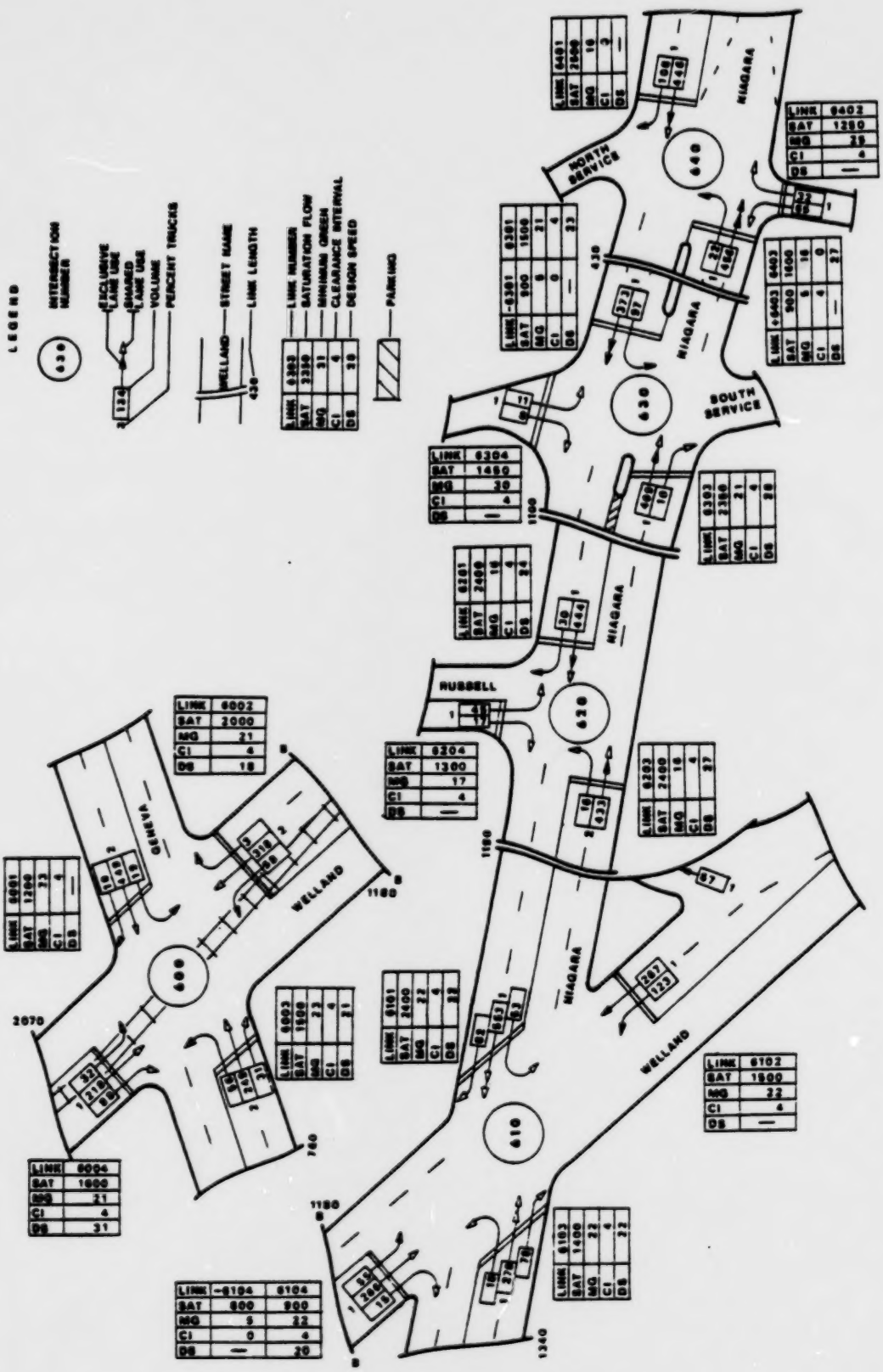

Figure A.15 - Series 600 Intersection Data

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	USER IDENTIFIABLE LINK NAME	PHASE NUMBER	SATURATION FLOW	MINIMUM GREEN	CLEARANCE INTERVAL
CARD COLUMN	4	5	10	15 20	25	30	35	40
FORMAT	A4	I1	I5	A10	I5	I5	I5	I5
	153	3	6001	WLLNDOS	2	1200	23	
	155	3	6002	ONVANW	1	2000	21	
	157	3	6003	QLLNDGN	2	1500	23	
	159	3	6004	ONVAWE	1	1600	21	
	161	3	6101	WLLNDNS	2	2400	22	
	163	3	6102	NIGRAWW	1	1500	22	
	165	3	6103	WLLNDN	2	1400	22	
	167	3	-6104	ADVNIGRAWE	1	800	5	
	168	3	6104	WIGRANE	1	900	22	
	170	3	6201	RUSSLMS	2	2400	16	
	172	3	6203	RUSSLMN	2	2400	16	
	174	3	6204	MIGRARE	1	1300	17	
	176	3	-6301	ADVSSERVNS	2	900	5	
	177	3	6301	SSERVNS	2	1500	21	
	179	3	6303	SSERVNN	2	2350	21	
	181	3	6304	NIGRASE	1	1450	30	
	183	3	6401	NSERVMS	2	2500	16	
	185	3	6402	MIGRANW	1	1250	25	
	187	3	-6403	DELNSERVMN	2	900	5	
	188	3	6403	NSERVMN	2	1600	16	

ENTRY	COUNT COLUMN	C* T	LINK NUMBER	UPSTREAM INT'N	LINK LENGTH	DESIGN SPEED	GEOMETRIC FEATURES	NUMBER OF LEFT TURNS	THRU VOLUME	NUMBER OF RIGHT TURNS	PERCENT TRUCKS AND BUSES	IMPORTANCE FACTOR MULTIPLIER	LEFT TURN SOURCE LINK	THRU MOVEMENT SOURCE	RIGHT TURN SOURCE LINK	FOURTH SOURCE LINK	MOVEMENT FROM 4TH SOURCE
CARD COLUMN	4	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
FORMAT	A4	I1	I5	I5	I5	I5	A6	I5	I5	I5	I5	I5	I5	I5	I5	I5	A6
	154	4	6001	0	0	0	LEFT	19	449	10	2						
	156	4	6002	610	1180	18	BOTH	58	318	3	2						
	158	4	6003	500	760	21	LEFT	56	249	31	2						
	160	4	6004	130	2070	31	LEFT	32	218	80	1						
	162	4	6101	620	1190	22		53	553	82	1						
	164	4	6102	0	0	0	LEFT	123	267	67	1						
	166	4	6103	510	1340	22		18	278	78	1						
	169	4	6104	600	1180	20	LEFT	55	266	15	1						
	171	4	6201	630	1100	24		0	444	30	1						
	173	4	6203	610	1190	27		16	433	0	2						
	175	4	6204	0	0	0	T	45	0	17	1						
	170	4	6301	640	430	23	LEFT	97	373	0	1						
	180	4	6303	620	1100	28		0	409	10	1						
	182	4	6304	0	0	0	T	11	0	0	1						
	184	4	6401	0	0	0		0	446	108	1						
	186	4	6402	0	0	0	T	65	0	32	1						
	189	4	6403	630	430	27	LEFT	22	456	0	1						

Figure A.16/ Series 600 Intersection Coding

A.7 SERIES 600 INTERSECTIONS

The five series 600 signals are located in the northeast corner of the network. The primary features include advanced and delayed greens. Figure A.15 illustrates the network; Figure A.16 the coding.

The delayed flashing green at intersection 640 is coded in a similar manner to advanced greens. Instead of the link number being preceeded by a negative sign however, a plus sign is coded instead. Data card structuring is also the same as for the advanced greens.

Of particular note is the fact that all left-turns for the priority greens are less than the 100 vehicles per hour which are assumed to be accomodated during the clearance interval. The following convention is then adopted by SSTOP. After discounting for the 100 vehicles per hour it is recognized that less than 15 vehicles remain to be cleared during the priority green which is the minimum number that SSTOP assumes must be designed for. Since exclusive left-turn lanes exist, 15 vehicles per hour are approximately equivalent to 15 tcu per hour. Therefore the V/S ratio for say link 6104 is 15/800 = 0.0188. This V/S ratio will then be used in calculating green time requirements. Should this value have been less than 0.01, SSTOP would have used a V/S of 0.01 in its calculations instead.

Figure A.17 provides sample output from the optimization run. Performance indicators and optimum signal settings are shown only for the optimum cycle length of 80 seconds.

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-NETWORK PARAMETERS
****

MINIMUM SYSTEM TRIAL CYCLE LENGTH = 60 SECONDS

CYCLE LENGTH INCREMENT = 10 SECONDS

MAXIMUM SYSTEM TRIAL CYCLE LENGTH = 80 SECONDS

MAXIMUM KIKOUT SIGNAL CYCLE LENGTH = 120 SECONDS

NUMBER OF LINKS IN NETWORK = 96

NUMBER OF INTERSECTIONS = 28

NETWORK STOP PENALTY = 4 SEC/STOP

NETWORK CLEARANCE INTERVAL = 4 SECONDS

DEFAULT TO IMPERIAL UNITS

OPTIMIZATION RUN. FULL OUTPUT FOR EACH TRIAL CYCLE

**OPTIONAL CARD 5 HAS NOT BEEN INCLUDED
THE FOLLOWING VALUES ARE ASSUMED

LEFT TURN TCU = 1.750

RIGHT TURN TCU = 1.250

TRUCK AND BUS PCU = 2.000

LEFT TURN VEHICLES CLEARED IN AMBER = 100 PER HOUR

PLATOON DISPERSION FACTOR = .25

Figure A.17 - Output for 80 Second Cycle

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.	LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLIER
100	1001	WLLNDOS	-	-	-	LEFT	10
	1002	ONTWW	120	1400	25	LEFT	10
	1003	WLLNDON	110	460	24	LEFT	10
	1004	ONTWE	-	-	-	LEFT	10
110	1101	PEDOS	100	460	19	-	10
	1103	PEDON	200	1410	24	-	10
	1104	ONTPED	-	-	-	-	10
120	1201	RT WLLNDLS	-	-	-	LEFT	10
	1205	L WLLNDLS	-	-	-	-	10
	1202	RT LAKEWW	130	1030	22	-	10
	1206	L LAKEWW	130	1030	22	LEFT	10
	1203	LAKEJN	310	1200	19	LEFT	10
	1207	JAMESLN	-	-	-	LEFT	10
	1204	LAKEWW	100	1400	20	LEFT	10
130	1301	WLLNDCS	-	-	-	-	10
	1302	CLARKWW	600	2070	25	LEFT	10
	1303	WLLNDCN	-	-	-	LEFT	10
	1304	CLARKWE	120	1030	17	-	10
200	2001	LAKEOS	110	1410	20	-	10
	2002	ONTLW	-	-	-	T	10
	2003	LAKEON	210	610	23	-	10
210	2101	KINGOS	200	610	15	ONE	10
	2102	LEFT ONTKW	220	240	20	T	10
	2106	RIGHTONTKW	220	240	20	T	10
220	2202	WLLMKW	320	310	27	-	10
	2203	KINGWN	230	860	18	-	10
230	2301	PAULOS	210	760	18	BOTH	10
	2303	PAULON	-	-	-	T	10
	2304	ONTPE	-	-	-	ONE	10
300	3001	CHURCHQS	-	-	-	-	10
	3002	QUEENCW	310	810	19	-	10
	3003	CHURCHQN	320	480	20	-	10
	3004	QUEENCE	-	-	-	-	10

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.	LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLER
310	3101	CHURCHJS	120	1200	17	-	10
	3102	JAMESCW	-	-	-	-	10
	3103	CHURCHJN	330	480	16	LEFT	10
	3104	JAMESCE	300	810	19	-	10
320	3201	KINGQS	300	480	14	-	10
	3202	QUEENKW	330	690	28	-	10
	3203	KINGJN	340	560	16	-	10
330	3301	KINGJS	310	480	25	RIGHT	10
	3302	JAMESKW	400	490	24	ONE	10
	3303	KINGJN	350	590	23	LEFT	10
340	5201	PAULQS	320	560	16	-	10
	5203	QUEENPE	230	600	18	-	10
350	5201	PAULJS	330	590	21	-	10
	5203	JAMESPE	340	530	18	-	10
400	4002	CRLILKW	410	300	22	-	10
	4003	KINGCN	430	580	20	T	10
410	4101	KINGAS	-	-	-	-	10
	4102	ACDMYKW	420	630	25	ONE	10
	4103	KINGAN	440	640	20	-	10
420	4201	COURTKS	-	-	-	-	10
	4202	KINGCW	500	790	22	ONE	10
	4203	COURTKN	-	-	-	-	10
430	4301	PAULCS	400	580	18	-	10
	4303	PAULCN	-	-	-	RIGHT	10
	4304	CRLILPE	500	510	21	ONE	10
440	4401	PAULAS	410	640	19	T	10
	4404	ACDMYPE	430	350	22	ONE	10
500	5001	CHRCHGS	600	760	12	-	10
	5002	GNVACW	510	420	19	LEFT	10
	-5003	ADVCHRCHGN					
	5003	CHRCHGN	520	620	28	LEFT	10

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.		LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLIER
510	5101		CHRCHNS	610	1340	21	RIGHT	10
	5102		NIGRACW	-	-	-	ONE	10
	5103		CHRCHNN	520	860	21	LEFT	10
520	-5201	ADV	PAULGS					
	5201		PAULGS	500	620	12	-	10
	5203		PAULGN	530	800	13	-	10
	5204	R	GNVAPE	440	890	20	-	10
	5208	TL	GNVAPE	440	890	20	LEFT	10
530	5301		RACEGS	520	800	23	-	10
	5302		GNVAGW	-	-	-	-	10
	5303		GALEGN	-	-	-	-	10
	5304		GNVARE	-	-	-	-	10
600	6001		WLLNDGS	-	-	-	LEFT	10
	6002		GNVAWW	610	1180	18	BOTH	10
	6003		WLLNDGN	500	760	21	LEFT	10
	6004		GNVAWE	130	2070	31	LEFT	10
610	6101		WLLNDNS	620	1190	22	-	10
	6102		NIGRAWW	-	-	-	LEFT	10
	6103		WLLNDNN	510	1340	22	-	10
	-6104	ADV	NIGRAWE					
	6104		NIGRAWE	600	1180	20	LEFT	10
620	6201		RUSSLNS	630	1100	24	-	10
	6203		RUSSLNN	610	1190	27	-	10
	6204		NIGRARE	-	-	-	T	10
630	-6301	ADV	SSERVNS					
	6301		SSERVNS	640	430	23	LEFT	10
	6303		SSERVNN	620	1100	28	-	10
	6304		NIGRASE	-	-	-	T	10
640	6401		NSERVNS	-	-	-	-	10
	6402		NIGRANW	-	-	-	T	10
	+6403	DEL	NSERVNN					
	6405		NSERVNN	630	430	27	LEFT	10

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
100	WLLNDOS	69	186	77	1	-	-	-	-	-
	ONTWW	78	193	68	1	1203	1202	1201	1207	(LEFT)
	WLLNDON	85	240	42	1	-	1103	-	-	-
	ONTWE	67	145	122	2	-	-	-	-	-
110	PEDOS	0	686	0	2	1002	1001	1004	-	-
	PEDON	0	367	0	2	-	2003	2002	-	-
	ONTPED	0	10	0	0	-	-	-	-	-
120	RT WLLNDLS	0	195	35	2	-	-	-	-	-
	L WLLNDLS	50	157	0	2	-	-	-	-	-
	RT LAKEWW	0	204	64	1	1303	1302	1301	-	-
	L LAKEWW	37	12	0	1	1303	1302	1301	-	-
	LAKEJN	64	196	35	4	3104	3103	3102	-	-
	JAMESLN	6	185	58	1	-	-	-	-	-
	LAKEWW	26	184	56	2	1001	1004	1003	-	-
130	WLLNDCS	51	95	10	0	-	-	-	-	-
	CLARKWW	112	246	14	0	6003	6002	6001	-	-
	WLLNDCN	30	30	96	0	-	-	-	-	-
	CLARKWE	8	235	34	0	1205	1204	1203	1207	(RIGHT)
200	LAKEOS	21	628	0	6	-	1101	-	-	-
	ONTLW	188	0	64	0	-	-	-	-	-
	LAKEON	0	54	41	0	-	-	2106	-	-
210	KINGOS	0	612	0	6	2002	2201	-	-	-
	LEFT ONTKW	439	0	0	3	2203	2202	-	-	-
	RIGHTONTKW	0	0	58	3	2203	2202	-	-	-
220	WLLMKW	0	667	58	3	3203	3202	3201	-	-
	KINGWN	57	316	0	1	2304	2303	-	-	-
230	PAULOS	130	502	231	4	2101	2101	-	-	-
	PAULON	35	0	329	1	-	-	-	-	-
	ONTPE	43	290	33	1	-	-	-	-	-
300	CHURCHOS	30	80	20	2	-	-	-	-	-
	QUEENOW	91	189	30	2	3103	3102	3101	-	-
	CHURCHON	3	48	60	2	-	3203	3202	-	-
	QUEENCE	4	195	29	2	-	-	-	-	-

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
310	CHURCHJS	41	156	56	4	1206	1205	1204	-	-
	JAMESCW	37	251	60	1	-	-	-	-	-
	CHURCHJN	29	162	70	3	-	3303	3302	-	-
	JAMESCN	28	176	128	1	3001	3004	3003	-	-
320	KINGQS	0	79	77	0	3002	3001	3004	-	-
	QUEENKW	173	494	125	2	3303	3002	3301	-	-
	KINGQN	44	77	0	0	3404	-	-	-	-
330	KINGJS	0	200	96	2	3102	3101	3104	-	-
	JAMESKW	154	578	103	2	4003	4002	-	-	-
	KINGJN	82	89	0	6	3504	-	-	-	-
340	PAULQS	287	0	0	1	3202	3201	-	-	-
	QUEENPE	125	626	0	1	2301	2304	2303	-	-
350	PAULJS	325	0	0	3	3302	3301	-	-	-
	JAMESPE	178	531	0	2	3401	3404	-	-	-
400	CRLILKW	78	626	0	1	4103	4102	4101	-	-
	KINGCN	243	0	0	2	4304	4303	-	-	-
410	KINGAS	0	66	78	1	-	-	-	-	-
	ACDMYKW	54	661	20	1	4203	4202	4201	-	-
	KINGAN	27	37	0	1	4404	-	-	-	-
420	COURTKS	0	65	73	0	-	-	-	-	-
	KINGCW	44	647	7	4	-5003	5002	5001	-	-
	COURTKN	72	75	0	0	-	-	-	-	-
430	PAULCS	34	87	0	1	4002	-	-	-	-
	PAULCN	0	112	44	2	-	-	-	-	-
	CRLILPE	50	785	140	2	3501	3504	-	-	-
440	PAULAS	80	0	0	2	4102	4101	-	-	-
	ACDMYPE	64	787	0	2	4301	4304	4303	-	-
500	CHRCHGS	0	465	157	1	6002	6001	6004	-	-
	GNVACW	368	823	66	2	5103	5102	5101	-	-
	ADVCHRCHGN	165	0	0	2	5208	5203	-	-	-
	CHRCHGN	0	306	0	2	5208	3203	-	-	-

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
510	CHRCHNS	0	0	739	3	6102	6101	6104	-	-
	NIGRACW	0	390	41	2	-	-	-	-	-
	CHRCHNN	10	370	0	2	-5201	5208	5203	-	-
520 ADV	PAULGS	125	0	0	1	5002	5001	-	-	-
	PAULGS	0	584	0	1	5002	5001	-	-	-
	PAULGN	25	323	159	2	5304	5303	5302	-	-
R	GNVAPE	0	260	45	3	4401	4404	-	-	-
TL	GNVAPE	101	174	0	3	4401	4404	-	-	-
530	RACEGS	8	625	0	2	-	-	5304	-	-
	GNVAGW	31	39	21	0	-	-	-	-	-
	GALEGN	129	628	79	1	-	-	-	-	-
	GNVARE	23	36	35	1	-	-	-	-	-
600	WLLNDNS	19	449	10	2	-	-	-	-	-
	GNVAWW	58	318	3	2	6103	6102	6101	-	-
	WLLNDGN	56	249	31	2	-	5003	5002	-	-
	GNVAWE	32	218	88	1	1301	1304	1303	-	-
610	WLLNDNS	53	553	82	1	-	6201	6204	-	-
	NIGRAWW	123	267	67	1	-	-	-	-	-
	WLLNDNN	18	278	78	1	-	5103	5102	-	-
ADV	NIGRAWE	55	0	0	1	6001	6004	6003	-	-
	NIGRAER	0	266	15	1	6001	6004	6003	-	-
620	RUSSLNS	0	444	30	1	-	6301	6304	-	-
	RUSSLNN	16	433	0	2	-6104	6103	6102	-	-
	NIGRARE	45	0	17	1	-	-	-	-	-
630 ADV	SSERVNS	97	0	0	1	6402	6401	-	-	-
	SSERVNS	0	373	0	1	6402	6401	-	-	-
	SSERVNN	0	409	10	1	6204	6203	-	-	-
	NIGRASE	11	0	8	1	-	-	-	-	-
640	NSERVNS	0	446	108	1	-	-	-	-	-
	NIGRANW	65	0	32	1	-	-	-	-	-
DEL	NSERVNN	22	0	0	1	6304	6303	-	-	-
	NSERVNN	0	456	0	1	6304	6303	-	-	-

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
100	1001	WLLNDOS	2	1400	11	4
	1002	ONTWW	1	1400	12	4
	1003	WLLNDON	2	1400	11	4
	1004	ONTWE	1	1300	12	4
110	1101	PEDOS	2	1500	0	4
	1102	PEDON	2	1500	0	4
	1104	ONTPED	1	1000	14	4
120	1201	RT WLLNDLS	2	1400	21	4
	1205	L WLLNDLS	2	850	21	4
	1202	RT LAKEWW	1	800	25	4
	1206	L LAKEWW	1	600	25	4
	1203	LAKEJN	2	1250	21	4
	1207	JAMESLN	3	1250	21	4
	1204	LAKEWW	1	1440	25	4
130	1301	WLLNDCS	2	1250	17	4
	1302	CLARKWW	1	1400	19	4
	1303	WLLNDCN	2	1700	17	4
	1304	CLARKWE	1	1400	19	4
200	2001	LAKEOS	2	1300	19	4
	2002	ONTLW	1	1600	14	4
	2003	LAKEON	2	1250	19	4
210	2101	KINGOS	2	2550	18	4
	2102	LEFT ONTKW	1	1950	16	4
	2106	RIGHTONTKW	1	800	16	4
220	2202	WLLMKW	1	2700	13	4
	2203	KINGWN	2	2550	17	4
230	2301	PAULOS	2	3200	20	4
	2303	PAULON	2	1250	20	4
	2304	ONTPE	1	1200	18	4

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
300	3001	CHURCHQS	2	1250	14	4
	3002	QUEENCW	1	1300	13	4
	3003	CHURCHQN	2	1250	14	4
	3004	QUEENCE	1	1300	13	4
310	3101	CHURCHJS	2	1350	17	4
	3102	JAMESCW	1	1650	17	4
	3103	CHURCHJN	2	1350	17	4
	3104	JAMESCN	1	1200	17	4
320	3201	KINGQS	2	1200	15	4
	3202	QUEENKW	1	2750	15	4
	3203	KINGQN	2	1200	15	4
330	3301	KINGJS	2	1350	18	4
	3302	JAMESKW	1	2750	16	4
	3303	KINGJN	2	1800	18	4
340	3401	PAULQS	2	1200	15	4
	3404	QUEENPE	1	2550	16	4
350	3501	PAULJS	2	1150	18	4
	3504	JAMESPE	1	2550	13	4
400	4002	CRLILKW	1	2460	17	4
	4003	KINGCN	2	1280	12	4
410	4101	KINGAS	2	950	14	4
	4102	ACDMYKW	1	2760	12	4
	4103	KINGAN	2	1000	14	4
420	4201	COURTKS	2	1175	14	4
	4202	KINGCW	1	2685	14	4
	4203	COURTKN	2	1100	14	4
430	4301	PAULCS	2	1100	18	4
	4303	PAULCN	2	1850	18	4
	4304	CRLILPE	1	2550	17	4

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
440	4401	PAULAS	2	1250	15	4
	4404	ACDMYPE	1	2800	12	4
500	5001	CHRCHGS	2	1650	18	4
	5002	GNVACW	1	2660	15	4
	-5003	ADVCHRCHGN	2	850	5	0
	5003	CHRCHGN	2	900	18	4
510	5101	CHRCHNS	2	2300	18	4
	5102	NIGRACW	1	2600	24	4
	5103	CHRCHNN	2	1360	18	4
520	-5201	ADV PAULGS	2	800	5	0
	5201	PAULGS	2	1600	20	4
	5203	PAULGN	2	2680	20	4
	5204	R GNVAPE	1	1400	20	24
	5208	TL GNVAPE	1	1400	20	24
530	5301	RACEGS	2	2800	15	4
	5302	GNVAGW	1	1300	20	4
	5303	GALEGN	2	2800	15	4
	5304	GNVARE	1	1300	20	4
600	6001	WLLNDGS	2	1200	23	4
	6002	GNVAWW	1	2000	21	4
	6003	WLLNDGN	2	1500	23	4
	6004	GNVAWE	1	1600	21	4
610	6101	WLLNDGS	2	2400	22	4
	6102	NIGRAWW	1	1500	22	4
	6103	WLLNDNN	2	1400	22	4
	-6104	ADVNIGRAWE	1	800	5	0
	6104	NIGRAWE	1	900	22	4
620	6201	RUSSLNS	2	2400	15	4
	6203	RUSSLNN	2	2400	15	4
	6204	NIGRARE	1	1300	17	4

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
630	-6301	ADVSSERVNS	2	900	5	0
	6301	SSERVNS	2	1500	21	4
	6303	SSERVNN	2	2350	21	4
	6304	NIGRASE	1	1450	30	4
640	6401	NSERVNS	2	2500	16	4
	6402	NIGRANW	1	1250	25	4
	+6403	DELNSERVNN	2	900	5	4
	6403	NSERVNN	2	1600	16	4

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

CYCLE LENGTH CALCULATIONS
****

INT'N NO.	SELECTED CYCLE LENGTHS		CALCULATED CYCLE LENGTHS				
	DESIRABLE CYCLE (SEC)	MINIMUM CYCLE (SEC)	MINIMUM CYCLE (SEC)	WEBSTER 0.9*cap (SEC)	WEBSTER 1.0*cap (SEC)	MIN GREEN 0.9*cap (SEC)	MIN GREEN 1.0*cap (SEC)
100	60	60	31	21	18	29	27
110	60	60	22	17	15	46	41
120	120	90	79	139	68	102	85
130	60	60	44	15	14	36	34
200	60	60	41	36	27	55	48
210	60	60	42	17	16	35	34
220	60	60	38	16	14	36	35
230	60	60	46	25	21	44	41
300	60	60	35	15	14	33	32
310	60	60	42	21	18	39	37
320	60	60	39	16	15	36	35
330	60	60	42	21	18	40	38
340	60	60	39	20	17	34	33
350	60	60	39	22	19	38	36
400	60	60	37	18	16	30	28
410	60	60	34	16	15	32	30
420	60	60	36	16	15	32	30
430	60	60	43	20	18	48	44
440	60	60	36	14	13	37	35
500	120	120	47	295	295	60	60
510	60	60	50	18	16	51	48
520	90	80	73	84	70	81	76
530	60	60	43	16	14	45	43
600	60	60	52	27	22	53	49
610	60	60	57	29	23	48	45
620	60	60	41	11	11	32	31
630	70	70	64	11	11	53	51
640	60	60	58	20	19	54	52

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

NETWORK CYCLE LENGTH = 80 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
100	1001	WLLNDOS	.253	.578	1.50	.36	266	-	-
	1002	ONTWW	.256	.554	1.39	.31	258	5.3	17.0
	1003	WLLNDON	.272	.622	1.45	.26	287	3.0	10.5
	1004	ONTWE	.286	.618	1.50	.45	279	-	-
110	1101	PEDOS	.466	.643	.67	.12	237	3.9	15.2
	1103	PEDON	.249	.343	.82	.05	211	4.9	19.8
	1104	ONTPED	.010	.057	.07	.00	8	-	-
120	1201 RT	WLLNDLS	.174	.633	2.33	.49	213	-	-
	1205 L	WLLNDLS	.248	.902	2.21	3.73	338	-	-
	1202 RT	LAKEWW	.358	.914	2.48	4.37	455	9.2	5.7
	1206 L	LAKEWW	.081	.207	.29	.02	32	.8	12.7
	1203	LAKEJN	.252	.916	3.32	4.52	467	11.4	5.9
	1207	JAMESLN	.212	.909	2.96	4.06	396	-	-
	1204	LAKEWW	.198	.506	1.97	.23	216	5.7	12.3
130	1301	WLLNDCS	.156	.462	1.01	.18	153	-	-
	1302	CLARKWW	.268	.476	.39	.12	111	6.3	23.0
	1303	WLLNDCN	.105	.311	.88	.06	132	-	-
	1304	CLARKWE	.208	.370	.70	.10	160	4.0	13.6
200	2001	LAKEOS	.542	.774	.72	.64	430	10.0	17.3
	2002	ONTLW	.157	.785	1.91	1.29	289	-	-
	2003	LAKEON	.084	.120	.01	.00	11	.5	22.5
210	2101	KINGOS	.254	.535	1.82	.15	353	6.7	10.6
	2102 LEFT	ONTKW	.231	.544	.77	.16	316	1.9	10.3
	2106 RIGHT	ONTKW	.075	.176	.07	.01	19	.2	12.5
220	2202	WLLMKW	.282	.501	1.72	.13	483	3.4	12.4
	2203	KINGWN	.164	.486	1.46	.13	123	5.0	12.2
230	2301	PAULOS	.280	.659	3.40	.32	730	10.6	11.7
	2303	PAULON	.294	.692	1.72	.70	303	-	-
	2304	ONTPE	.324	.682	1.59	.66	301	-	-

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

NETWORK CYCLE LENGTH = 80 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
300	3001	CHURCHQS	.128	.465	.96	.18	133	-	-
	3002	QUEENCW	.302	.483	.55	.11	132	3.2	15.0
	3003	CHURCHQN	.104	.378	.59	.06	109	1.1	8.8
	3004	QUEENCE	.187	.299	.42	.06	112	-	-
310	3101	CHURCHJS	.229	.611	1.57	.43	250	5.4	10.7
	3102	JAMESCW	.238	.453	1.16	.17	244	-	-
	3103	CHURCHJN	.212	.565	1.29	.18	230	3.0	8.0
	3104	JAMESCN	.323	.615	1.16	.24	231	4.1	12.5
320	3201	KINGQS	.146	.508	.60	.15	129	1.8	8.0
	3202	QUEENKW	.305	.498	.93	.13	172	4.8	21.7
	3203	KINGQN	.128	.445	.58	.10	124	1.5	8.6
330	3301	KINGJS	.241	.603	1.21	.23	265	2.5	10.7
	3302	JAMESKW	.309	.618	2.08	.25	356	5.6	13.9
	3303	KINGJN	.100	.250	.15	.01	17	1.0	19.2
340	3401	PAULQS	.241	.603	.85	.10	159	2.9	10.7
	3402	QUEENPE	.297	.594	1.27	.05	201	6.1	14.1
350	3501	PAULJS	.291	.647	.60	.09	153	2.4	15.0
	3504	JAMESPE	.283	.629	2.06	.27	331	6.3	11.3
400	4002	CRLILKW	.297	.540	.92	.15	140	2.9	13.9
	4003	KINGCN	.193	.551	.36	.27	189	1.9	14.3
410	4101	KINGAS	.173	.494	.84	.22	129	-	-
	4102	ACOMUKW	.275	.500	.83	.12	168	4.5	19.7
	4103	KINGAN	.085	.243	.26	.02	57	.7	11.6
420	4201	COURTKS	.132	.364	.73	.09	113	-	-
	4202	KINGCW	.275	.512	2.18	.24	471	7.2	14.6
	4203	COURTKN	.182	.502	.99	.23	156	-	-

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

NETWORK CYCLE LENGTH = 80 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
430	4301	PAULCS	.134	.596	.47	.22	120	1.4	9.3
	4303	PAULCN	.085	.378	1.03	.10	133	-	-
	4304	CRLILPE	.408	.604	.95	.20	588	5.6	16.7
440	4401	PAULAS	.065	.325	.66	.04	74	1.2	8.0
	4404	ACDMYPE	.315	.450	.65	.09	133	3.3	17.1
500	5001	CHRCHGS	.404	1.077	6.55	8.12	1088	22.1	4.0
	5002	GNVACW	.488	1.084	11.50	8.12	1847	24.9	4.0
	-5003	ADVCHRCHGN	.197	2.627	1.08	3.65	215	5.4	3.6
	5003	CHRCHGN	.346	.716	1.91	.81	247	4.0	9.0
510	5101	CHRCHNS	.330	.562	.64	.08	178	9.6	19.4
	5102	NIGRACW	.173	.554	2.57	.31	373	-	-
	5103	CHRCHNN	.237	.403	.72	.12	174	3.3	15.6
520	-5201	ADV PAULGS	.157	3.140	.34	.51	50	2.1	7.1
	5201	PAULGS	.368	.800	3.40	1.44	527	10.6	6.5
	5203	PAULGN	.215	.581	3.64	.36	462	9.9	7.7
	5204 R	GNVAPE	.232	.892	2.89	3.33	448	8.8	5.8
	5208 TL	GNVAPE	.202	.777	2.43	1.22	295	6.0	7.8
530	5301	RACEGS	.232	.357	1.04	.09	296	5.3	18.1
	5302	GNVAGW	.091	.364	.73	.09	97	-	-
	5303	GALEGN	.343	.528	1.79	.27	511	-	-
	5304	GNVARE	.093	.372	.75	.10	99	-	-
600	6001	WLLNDGS	.408	.710	1.49	.78	351	-	-
	6002	GNVAWW	.193	.594	1.35	.22	268	6.3	13.5
	6003	WLLNDGN	.233	.405	.82	.12	193	3.3	14.9
	6004	GNVAWE	.227	.698	1.56	.39	295	6.2	21.3
610	6101	WLLNDNS	.314	.785	2.82	.74	630	10.6	14.6
	6102	NIGRAWW	.319	.823	2.64	1.73	503	-	-
	6103	WLLNDNN	.293	.733	1.26	.51	329	6.1	15.6
	-6104	ADVNIGRAWE	.070	1.120	.14	.06	17	.8	15.1
	6104	NIGRAWE	.319	.638	.21	.27	168	3.6	17.4

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

NETWORK CYCLE LENGTH = 80 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
620	6201	RUSSLNS	.202	.294	1.00	.03	316	5.1	19.2
	6203	RUSSLNN	.195	.284	.30	.03	185	4.1	24.8
	6204	NIGRARE	.048	.226	.41	.03	51	-	-
630	-6301	ADVSSERVNS	.108	2.160	.15	.07	19	.6	13.9
	6301	SSERVNS	.251	.410	.42	.08	159	1.8	16.8
	6303	SSERVNN	.181	.353	1.53	.05	290	4.7	18.6
	6304	NIGRASE	.013	.045	.10	.00	13	-	-
640	6401	NSERVNS	.234	.506	2.21	.23	410	-	-
	6402	NIGRANW	.078	.251	.50	.04	72	-	-
	+6403	DELNSERVNN	.024	.320	.13	.03	14	.2	7.9
	6403	NSERVNN	.288	.490	.13	.13	262	1.6	22.7

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

```
**********************
*                    *
*  CALCULATED        *
* SIGNAL TIMINGS     *
*                    *
*   CY = 80 SEC      *
**********************
```

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET NO. SEC(PERCNT)	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
100	80	14(17)	1	1002	CNTWW	37(46)	4(5)
				1004	CNTWE		
			2	1001	WLLNDCS	35(44)	4(5)
				1003	WLLNDCN		
110	80	20(25)	1	1104	CNTPEC	14(17)	4(5)
			2	1101	PEDOS	58(71)	4(5)
				1103	PEDCN		
120	120	*** ***	1	1202 RT	LAKEWW	47(37)	4(3)
				1206 L	LAKEWW		
				1204	LAKEWW		
			2	1201 RT	WLLNDLS	33(27)	4(3)
				1205 L	WLLNDLS		
				1203	LAKEJN		
			3	1207	JAMESLN	28(23)	4( )
130	80	74(92)	1	1302	CLARKWW	45(56)	4(5)
				1304	CLARKWE		
			2	1301	WLLNOCS	27(34)	4(5)
				1303	WLLNOCN		
200	80	62(77)	1	2002	ONTLW	16(20)	4(5)
			2	2001	LAKEOS	56(70)	4(5)
				2003	LAKEON		
210	80	62(85)	1	2102 LEFT	CNTKW	34(42)	4(5)
				2106 RIGHT	CNTKW		
			2	2101	KINGOS	38(46)	4(5)
220	80	58(72)	1	2202	WLLMKW	45(56)	4(5)
			2	2203	KINGWN	27(34)	4(5)

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

```
**********************
*                    *
*  CALCULATED        *
* SIGNAL TIMINGS     *
*                    *
*   CY = 80 SEC      *
**********************
```

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET SEC(PERCNT)	NO. PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
230	80	7(8)	1	2304	CNTPE	38(46)	4(5)
			2	2301	PAULOS	34(42)	4(5)
				2303	PAULON		
300	80	79(98)	1	3002	QUEENCW	50(61)	4(5)
				3004	QUEENCE		
			2	3001	CHURCHCS	22(27)	4(5)
				3003	CHURCHCN		
310	80	74(92)	1	3102	JAMESCW	42(51)	4(5)
				3104	JAMESCN		
			2	3101	CHURCHJS	30(37)	4(5)
				3103	CHURCHJN		
320	80	38(47)	1	3202	QUEENKW	49(61)	4(5)
			2	3201	KINGJS	23(29)	4(5)
				3203	KINGJN		
330	80	30(37)	1	3302	QUEENPE	40(50)	4(5)
			2	3301	KINGJS	32(40)	4(5)
				3303	KINGJN		
340	80	61(76)	1	3404	QUEENPE	40(50)	4(5)
			2	3401	PAULCS	32(40)	4(5)
350	80	66(82)	1	3504	JAMESPE	36(45)	4(5)
			2	3501	PAULJS	36(45)	4(5)
400	80	29(36)	1	4002	CRLILKW	44(55)	4(5)
			2	4003	KINGCN	28(35)	4(5)

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

```
**********************
*                    *
*  CALCULATED        *
* SIGNAL TIMINGS     *
*                    *
*   CY = 80 SEC      *
**********************
```

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET SEC(PERCNT)	NO. PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
410	80	27(33)	1	4102	ACOMYKW	44(55)	4(5)
			2	4101	KINGAS	28(35)	4(5)
				4103	KINGAN		
420	80	15(18)	1	4202	KINGCW	43(54)	4(5)
			2	4201	COURTKS	29(36)	4(5)
				4203	COURTKN		
430	80	1(1)	1	4304	CRLILPE	54(66)	4(5)
			2	4301	PAULCS	18(22)	4(5)
				4303	PAULCN		
440	80	0(0)	1	4404	ACOMYPE	56(70)	4(5)
			2	4401	PAULAS	16(20)	4(5)
500	120	*** ***	1	5002	GNVACW	54(43)	4(3)
			2	-5003	ADVCHRCHGN	9(7)	4(3)
				5001	CHRCHGS	45(37)	4(3)
				5003	CHRCHGN		
510	80	34(42)	1	5102	NIGRACW	25(31)	4(5)
			2	5101	CHRCHNS	47(59)	4(5)
				5103	CHRCHNN		
520	100	*** ***	1	5204 R	GNVAPE	26(26)	24(24)
			2	5208 TL	GNVAPE		
				-5201 ADV	PAULGS	5(5)	4(4)
				5201	PAULGS	37(37)	4(4)
				5203	PAULGN		

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

```
**********************
*                    *
*  CALCULATED        *
* SIGNAL TIMINGS     *
*                    *
*   CY = 80 SEC      *
**********************
```

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET SEC(PERCNT) NO.	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
530	80	*** ***	1	5302	GNVAGW	20(25)	4(5)
				5304	GNVARE		
			2	5301	RACEGS	52(65)	4(5)
				5303	GALEGN		
600	80	30(37)	1	6002	GNVAWW	26(32)	4(5)
				6004	GNVAWE		
			2	6001	WLLNOGS	46(56)	4(5)
				6003	WLLNOGM		
610	80	62(77)	1	-6204	ADVNIGRAWE	5(6)	4(5)
				6102	NIGRAWW	31(39)	4(5)
				6104	NIGRAWE		
			2	6101	WLLNONS	32(40)	4(5)
				6103	WLLNONN		
620	80	36(45)	1	6204	NIGRARE	17(21)	4(5)
			2	6201	RUSSLNS	55(69)	4(5)
				6203	RUSSLNN		
630	80	69(86)	1	6304	NIGRASE	23(29)	4(5)
			2	-6301	ADVSSERVNS	4(5)	4(5)
				6301	SSERVNS	41(51)	4(5)
				6303	SSERVNN		
640	80	0(0)	1	6402	NIGRANW	25(31)	4(5)
			2	6401	NSERVNS	37(45)	4(5)
				6403	NSERVNN		
				+6403	DELNSERVNN	6(7)	4(5)

Figure A.17 - Output for 80 Second Cycle (continued)

ST. CATHARINES EXAMPLE NETWORK - CBD - AM PEAK

TOTAL SYSTEM PERFORMANCE VALUES
****

TRIAL CYCLE LENGTH (SEC)	NO. OF KICKED OUT SIGNALS	TOTAL DELAY (TCU-HRS/HR)		TCU STOPS PER HOUR	PERF. INDEX	TOTAL INTRNL TRAVEL TIME (TCU-HRS/HR)	AVG. SYSTEM SPEED (MPH)
		UNIFORM	RANDOM				
80	4	131.2	62.5	24849	221.2	340.0	12.0

THE OPTIMUM CYCLE IS 70 SECONDS

Figure A.17 - Output for 80 Second Cycle (continued)

APPENDIX B - SPECIAL PARAMETERS
(Prepared by J. Lam)

B.1 SATURATION FLOW

The amount of traffic that can pass through a signal controlled intersection from a given approach depends on the green time available to the traffic and on the maximum flow of vehicles past the stop line during the green period.

When the green period commences, vehicles take some time to start and accelerate to normal running speed, but after a few seconds the queue discharges at a more or less constant rate called the saturation flow. The saturation flow is the flow which would be obtained if there was a continuous queue of vehicles and they were given a 100 percent green time. It is generally measured in vehicles per hour of green time, but actual units depend upon the procedure used in determining the saturation flow. A more general use of saturation flow is obtained if it is expressed in terms of through car units per hour as these units make saturation flow independent of the traffic stream composition. Saturation flow can be measured directly from the field or estimated from various models based on past empirical studies. A few techniques are described in more detail in the following paragraphs. It may prove beneficial to the user to test each of the following procedures to determine which provides the best estimate of field conditions. Otherwise it is suggested that the Toronto equation be used since it has been calibrated for Canadian conditions (at least in Toronto).

B.1.1 British Method

Based on field studies and controlled experiments carried out in England, Webster [4] developed the following equation for saturation flow as a function of approach width:

$$S = 160\ W \text{ passenger car units (pcu) per hour.}$$

where S = saturation flow in pcu per hour of green
W = approach width in feet

This equation is applicable for approach widths between 17 and 60 feet. For widths under 17 feet, the following table of values is suggested:

W:	10	11	12	13	14	15	16	17
S:	1850	1875	1900	1950	2075	2250	2475	2700

The saturation flow values thus obtained are then adjusted to allow for various geometric and traffic factors.

(a) Gradient: The saturation flow is reduced by 3% for each 1% of uphill gradient, and increased by 3% for each 1% downhill gradient; where the gradient is defined as the average slope between the stopline and a point 200 feet before the approach.

(b) Traffic composition: The effect of different types of vehicles on the saturation flow at traffic signals is given by the following pcu equivalents:

1 heavy or medium truck	= 1.75 pcu
1 bus	= 2.25 pcu
1 light truck	= 1 pcu
1 motorcycle	= 0.33 pcu
1 bicycle	= 0.20 pcu

(c) Right-turns: Each right-turn vehicle is equivalent to 1.25 straight-through vehicle. This case also covers left-turns without any opposing flow.

(d) Left-turns (with opposing flow): The left-turn saturation flow (Sr) is given by:

$$Sr = 3600\ Nr/\ \frac{gs-qc}{s-q}$$

where Nr = number of left-turns per cycle
g = effective green time
c = cycle length
q = opposing flow rate
s = opposing saturation flow

(e) Parking: Effect of a parked vehicle. It has been found that the reduction in saturation flow caused by the parked car nearest to the stop line on the particular approach is equivalent to a loss of approach width at the stop line, and can be expressed approximately as follows:

Effective loss of approach width

$$= 5.5 - \frac{0.9(z - 25)}{k} \text{ ft (if positive)}$$

where z is the clear distance of the nearest parked car from the stop line (ft) and k is the green time (seconds). If the expression becomes negative, the effective loss should be taken to

be zero. This equation must be calibrated if metric units are employed.

(f) Site characteristics: the adjustment factors for good, average and poor sites are 120%, 100% and 85% of the original saturation flow values. These are used to account for pedestrian activities, road alignment visibility and illegal parking. The adjustments are rather arbitrary and should be used with caution, preferably in conjunction with field checks.

B.1.2 Australian Methods

The Australian Road Research Board (ARRB) (9) developed the following table of saturation flow values in through car units (tcu) per hour of green for different lane types in different urban areas.

	Lane Type		
Environment	Curbs	Centre	Median
CBD	1270	1580	1550
Industrial	1570	1700	1670
Suburban Shopping	1570	1810	1770
Residential	1700	1850	1810

The above environments are characterized by the following traffic effects:

1. CBD - large number of pedestrians, high parking turnover, cars and taxis picking and letting off passengers, buses, some loading and unloading of commercial vehicles.

2. Industrial - smaller number of pedestrians than CBD, interference caused by loading and unloading of goods, vehicles entering and leaving premises, a low parking turnover.

3. Suburban Shopping - moderate pedestrian movements and moderate parking turnover.

4. Residential - very few pedestrians and almost no interference due to loading/unloading or parking turnover.

With respect to the lane types, mentioned in the table, it should be emphasized that these values are dependent only on the position of the lane on approach (e.g., curb lane has sewer holes and interference from pedestrians). The additional time required for turning vehicles is accounted for in the conversion of turning volumes to equivalent through car units (tcu).

The saturation flow for a multi-lane approach is simply the sum of the values for the individual lanes. It is obvious that this method places the emphasis on the number of lanes on an approach rather than the overall approach width. It is, therefore, more appropriate in urban areas where traffic lanes are well designated and there are strong lane disciplines.

However, some adjustments are necessary when lane widths are non-standard, and the adjustment factors are provided in the following table:

Lane Width (ft)	8	9	10-12	13	14	15
(m)	2.4	2.7	3.0-3.7	4.0	4.3	4.6
Factor	.88	.93	1.00	1.03	1.045	1.06

Finally, allowance for gradient can be made by adjusting the saturation flow value 1% downward for each 1% upgrade and 1% upwards for each 1% downgrade.

B.1.3 Field Measurement of Saturation Flow

Studies to determine the saturation flow value of an intersection usually require two people for two lanes of traffic. Precise manpower requirements are outlined in Table B.1. One person is effectively a time/recorder, and the other is a counter. The timer gives an appropriate signal such as 'now' or 'time' every five seconds beginning at the start of the green aspect and ending when the amber phase is over. Intervals of five seconds are typically used because they are convenient for the recorder and counter without either one being rushed at their task. At the end of each interval, when signalled to do so, the counter gives the number of cars in each lane that have passed over the stop bar during the interval. The counts are given in a predetermined order such as median lane first, then curb lane. The numbers are then recorded by the time. Any right or left-turning vehicles, trucks, or buses must also be recorded separately in the interval in which they occur. It is also important that the initial queue length, before the signal changes to green, as well as the length of the queue at the end of the all red indication, be recorded for each lane. To simplify this task, if a lane has more than five vehicles in the queue then this is coded as a check mark ( ) and if there are fewer than five vehicles in the lane then the actual lane count is recorded. This is used later to determine if saturation flow has ended during the green or if it continued to the end of amber. A sample field sheet used to determine saturation flow is given in Table B.2.

Table B.1 Manpower Requirements For Saturation Flow Studies

Number of through lanes on one approach	Exclusive turn lanes		Right turn volume		Manpower	Manhours (a.m. & p.m. total)
	Left	Right	Light	Heavy		
1 or 2					2	6-7
1 or 2	X		X		2	6-7
1 or 2		X	X		2	6-7
1 or 2	X	X	X		2	6-7
2		X		X	3	9-11
2	X	X		X	3	9-11
3 or more					3	9-11

Table B.2/ Sample Saturation Flow Data Field Sheet

PX NAME BLOOR & SHERBOURNE
PX #252
DIRECTION W/B
OF LANES 2
OBSERVERS A.H. & B.S.

DATE JAN. 9/75
PERIOD A.M.
CYCLE (Green time) 43 sec.
LANE & APPROACH WIDTHS 33'
ROAD CONDITION wet

INIT. QUEUE		NUMBER OF VEHICLES PER 5 SECOND INTERVAL																												QUEUE AT END OF ALL RED	
		0-5			6-10			11-15			16-20			21-25			26-30			31-35			36-40			41-45			Amber			
		1	2		1	2		1	2		1	2		1	2		1	2		1	2		1	2		1	2		1	2		
✓	✓	2	1		2	2		3	2		2	1	1	1	1		1	3		1	2		1	2		2	2		0	1		1	1
✓	✓	2	1		2	2		2[T]	2[T]		3	2		2	1[T]		1	2		1	2		2	2		2	2		2	1		1	0
✓	✓	2	1		3	2		1	0		2	0		0	1		1	0		0	1		1	1		2	2		1	0		0	0
✓	✓	2	2		2	2		2	1		2	3		2	1[B]		3	1		2	0		2	2		1	1		2	1[B]		1	1
✓	✓	2	2		2	2		2	0	1	3	2		3	2[T]		2	2		3	1	1	2	3		2	2		0	0		0	0
✓	✓	2	2		2	2		2	1		2	2		3	2	1	2	1		3	2		2	2		1	1		1	0		0	1
✓	4	1	1		2	2		3	3		2	2		3	3		1	2		1	3		2	2		2	1		1	1		0	0
✓	✓	2	2		1	2		2	2		2	2		2	3		1	2		2	3[B]		3	3		1	0		1	1		0	0
✓	✓	2	2		2	1	1	2	2		3	3		2	3		2	1	2	2	2		2	1		2	2		1	1		0	1
✓	✓	2	1		2	3		3	2		2	1	1	2	2		2	3		2	2		3	2		2	2		1	1		1	0
✓	✓	2	2		2	2		2	2	1	3	2		3	3		2	2		3	2		3	3		1	1		2	2		2	1
✓	✓	2	1		1	2		2	2		2	2		3	2		3	3		2	1		2	3		2	1		2	1		2	1
✓	✓	2	2		2	2		2	2		1	2		2	2		2	1		3	3		2	2		2	0		1	0		0	0
✓	✓	2	2		2	2		3	3		2	2		3	2		1	3		2	2		2	3		2	1		1	2		1	1
✓	✓	2	2		2	0	1	2	2		3	2		2	2		2	2		1	2		3	1		1	1		1	1[T]		0	1
✓	✓	2	2		3	2		2	2		3	2		2	2	1	2	2		3[T]	2		3	3		2	1		0	0		0	0
✓	✓	2	2		2	3		3	2	1	2	2		3	2		2	3		3	2		2	2		3	2		0	0		1	1
✓	✓	2	2		2	2		3	3		2	2		3	3		3	2[T]		3	2		3	2		1	2		0	0		1	0
✓	✓	2	2		2	2	1	2	1	1	3	2		3	3		2	2		2	1	1	2	2		2	1		1[T]	0		1	1
✓	✓	2	1[T]		2	2		2	2		3	2[T]		2	2		3	0		1	1		1	1		1	2		1	0		0	1
✓	✓	2	2	1	1	1		3	3		2	2		3	3		3	2		2	2		2	2	1	2	2		1	0		0	0
✓	4	1	1		2	2		2	3		2	2		3	3		2	3		2	2		2	2		2	1	1	0	1		0	0
✓	✓	1	1		2	2		2	2		3	2[B]		2	2		3	1		2	1		2	2		2	2		0	0		1	1
✓	✓	1	1		3	3		2	1		3	1[B]		3	0	1	3	2		2	2		1	0		1	0	1	1[T]	0		0	1
✓	✓	2	1		2	3		2[T]	3		1	2		2	2		2	1		3	2		2	2		2	2		0	1		1	2
✓	✓	2	1[B]		2	3		3	1[T]		2	1		2	2		2	2	1	3	1	1	2	2		2	2		1	0		1	0
#		26	26		26	26		26	25		26	25		25	25		22	24		21	24		20	22		16	15		11	10			
P.C.		48	34		52	53		57	47		60	45		61	50		49	47		49	43		46	49		31	26		12	10			
T & B			2					2	2			3			3			1		1	1								1	1			
R			1			3			3			2			3			3			3			1			1						
PCU		48	44		52	59		61	55		60	54		61	60		49	53		51	49		46	50		31	27		14	12			
PCU / INT		1.85	1.69		2.00	2.19		2.35	2.20		2.31	2.16		2.44	2.40		2.23	2.21		2.43	2.64		2.30	2.27		1.94	1.80		1.27	1.20			

The rule used to determine the end of saturation flow within any one cycle is a recorded count of 1 passenger car per lane or less for two consecutive intervals. If the count falls to 1 or 0 for only one interval, then saturation flow is not necessarily over since the gap could be due to a variety of temporary causes and saturation flow could continue thereafter. If two consecutive intervals of one passenger car per lane or less are inadvertently recorded on the field sheet, then all counts in that lane should be omitted from the analysis beginning at the first interval with flow less than the saturation criterion level.

An exception to this rule is if the two consecutive undersaturated intervals fall at the beginning of the green indication. In this case the count should be continued to allow saturation flow to commence. This rule of terminating the count for any cycle if saturation flow has begun, even if late, and has subsequently ended is useful in determining the effects of progression, gradient and a small initial queue on saturation flow values, as well as lost time at the beginning of green.

After the cycle by cycle data reduction is complete, the overall study data is summarized into a format suitable for calculations. Depending on how the final results are to be used. two different reduction techniques may be employed. The first merely involves the determination of approach capacity in vehicles per hour of green while the second requires the conversion to'through car units' (tcu) for comparison or calibration of local results with a theoretical method. In either case, 5 rows should be left blank at the bottom of each field sheet for final data reduction. This leaves 40 rows for recording purposes which is the usual number collected during a typical field study, thus providing an adequate sample size upon which to base conclusions. Capacity in vehicles per hour of green is obtained as follows:

1. Determine the acceptable number of samples or rows (R) within each 5 second interval for the individual lanes. Some entries may be deleted because of a discharge rate below the saturation criterion level, therefore R is not constant for every interval or lane.

2. Sum the total number of vehicles (V) irrespective of type or turning movement, recorded during each 5-second interval for the individual lanes.

3. Calculate the average number of vehicles per interval per lane

$$A_i = \frac{V}{R}$$

These values may be plotted on a histogram to give a visual impression of saturation flow for an average cycle on the lanes under investigation.

4. Calculate the average saturation value for all 5-second intervals combined for each lane

$$\sum_{n}$$

$$S = \frac{\sum_{i=1}^{n} \Lambda_i}{n}$$

where n = the number of 5-second intervals within the green and amber intervals of the cycle.

5. Calculate the capacity in vehicles per hour of green:

$$C = S \times 720$$

The above technique is illustrated in Figure B.1.

If it is desirable to convert the field data from vehicles to passenger car units (pcu), or through car units, the following technique should be employed. Instead of summing the total number of vehicles in step (2) above, determine the number of passenger cars (PC), trucks (T), and buses (B) separately. Passenger car units are then obtained by using a conversion factor of 1.75 for heavy trucks and 2.25 for buses. Therefore:

$$pcu = PC + 1.75 \Sigma T + 2.25 \Sigma B$$

To simplify the calculations, a factor of 2.0 may be used for the total number of trucks and buses combined, as is assumed in SSTOP in converting vehicular flow to tcu's. The actual factor should be equivalent to that used on card type 5, columns 16-20.

Through car units are determined by using a conversion factor of 1.25 for right turns (R) and 1.75 for left turns (L), or the values entered on card type 5 columns 11-15 and 6-10 respectively.

Therefore:

$$tcu = pcu + 1.25 \Sigma R + 1.75 \Sigma L$$

PX NAME Bloor & Sherbourne CYCLE (GREEN TIME) 43 sec.

PX NUMBER 252 PERIOD A.M.

DIRECTION WB ROAD CONDITIONS Wet

LANE WIDTHS: 1. 11' 2. 12' 3. 10'

LANE (1)	VEHICLES /INTERVAL (2)	COMPARISON FACTOR	SATURATION FLOW VEH/HR.GR	LOST TIME (3) INITIAL	FINAL
	(a)			(b)	
1	2.25	720	1620	.89	2.18
2	2.23	720	1608	1.22	2.36
3					

(a) $$\frac{1.85 + 2.00 + 2.35 + \ldots + 1.94 + 1.27}{8}$$

(b) $$5 - \frac{(3600)(1.85)}{1620} = 0.89$$

(1) Lane Code: 1 = Curb 2 = Next 3 = Next
(2) Pcu or tcu may be substituted here
(3) Lost time = t - 3600n/s
where: t = interval length (5 seconds)
n = # of vehicles discharged in time t
s = saturation flow (vehicles/hour green)

Figure B.1 - Saturation Flow Summary

It is assumed in the above equation that left and right turns were recorded separately and do not form part of the pcu value. The above conversion factors are somewhat arbitrary and therefore should be calibrated for local conditions. Both may be considered on a subjective basis in the terms of their interference with the main stream of traffic. If the turning radii are small or there is a significant amount of interference from pedestrians or opposing traffic, then all turns should be converted using the appropriate factors. If no interference is encountered and traffic flows freely regardless of the turns, then no conversion is necessary.

After all conversions are complete, the same steps are taken as outlined above to obtain the capacity of the individual lanes or total approach in pcu or tcu per hour of green.

B.1.4 TORONTO METHOD

The following document is the complete "Metropolitan Toronto Intersection Capacity Guide" as provided by the Metropolitan Toronto Roads and Traffic Dept.

Appendix B.1.4 Toronto Method

THE METROPOLITAN TORONTO INTERSECTION CAPACITY GUIDE

Fourth Edition - August 1982

David B. Richardson, P. Eng.
Municipality of Metropolitan Toronto
Traffic Control Centre

PREFACE

The following values for saturation flow, together with the subsequent capacity calculations and volume/capacity ratios are intended as a guide for both estimating the capability of an at-grade signalized intersection to handle vehicular traffic, and evaluating the amount of spare capacity available for future growth of traffic at the intersection. In addition, it enables the user to optimize the performance of the signals by "balancing" the volume/capacity ratios, thereby achieving the minimum delay for each of the competing vehicular movements. The saturation flow regression equations are based on extensive research into field measurement techniques, augmented by an in-depth data collection program over the past eight years. This empirical approach has a sound theoretical basis, however, since the techniques are founded on the Australian Road Research Board method.

Although these techniques provide accurate and reliable values if used correctly, they should always be supplemented, where possible, with actual field data or at least some brief observations to confirm with geometric layout, pavement markings, and general traffic characteristics that cannot be derived from a blueprint or historical counts.

The methodology outlined in the guide will provide reasonable values for the majority of geometric and signal phasing configurations throughout Metropolitan Toronto. Additional interpretation may be required in some cases, however, to determine the impact of excessively wide lanes, turning radii, storage space, and on-street parking. A simple table look-up procedure cannot replace sound engineering judgement, which must be used in many instances where a "textbook case" does not exist. Care must be exercised in all cases therefore, to ensure precise and dependable results.

The material contained in this report has been prepared by the staff of the Traffic Control Centre, Traffic Branch, Metropolitan Toronto Roads and Traffic Department under the guidance of David B. Richardson, Senior Traffic Engineer. Ongoing research in the field of intersection capacity may lead to further refinements of the various concepts and parameters contained in this document. In this regard the Department would welcome any comments regarding the Metropolitan Toronto Intersection Capacity Guide.

TABLE OF CONTENTS

	Page Number	
Preface	i	(128)
Introduction	1	(130)
Part I: Determination of Saturation Flow	1	(130)
Step 1: Initial A.R.R.B. Saturation Values	2	(131)
Step 2: Public Transit Stop Adjustments	2	(131)
Step 3: A) Lane Width Adjustment	3	(132)
B) Gradient Adjustment	3	(132)
C) Pedestrian Adjustment	3	(132)
D) Parking Adjustment	4	(133)
Step 4: "Toronto" Saturation Flow Values	6	(135)
Step 5: Special Lane Types	7	(136)
A) Exclusive Right Turns	7	(136)
B) Unopposed Left Turns	7	(136)
C) Right-Turn Cutoff	8	(137)
D) Shared Left and Right Turns	8	(137)
E) Left or Right-Turn Tunnel	8	(137)
F) Double Right Turns	8	(137)
G) Double Left Turns	8	(137)
Part II: Determination of Capacity	10	(139)
Part III: Volume/Capacity Ratios	12	(141)
Part IV: Worked Example	14	(143)
Part V: Balancing V/C Ratios and Determining Reserve Capacity	22	(151)
Part VI: List of Variables Used in this Guide	25	(154)

PREVIOUS EDITIONS

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THE TORONTO INTERSECTION CAPACITY GUIDE

INTRODUCTION

The capacity of any approach to an intersection is defined as "the maximum number of vehicles which has a reasonable expectation of clearing during a given time period." At a signalized intersection, the capacity is dependent on the green time available per cycle and the maximum flow of vehicles past the stop line during the green indication. When the green period commences, vehicles take some time to start and accelerate to normal running speed, but after a few seconds the queue discharges at a relatively constant rate called "saturation flow". Therefore, saturation flow is defined as"the flow which would be obtained if there was a continuous queue of vehicles and they were given 100 per cent green time."

PART I: DETERMINATION OF SATURATION FLOW

There are several methods of estimating saturation flow, but the Australian Road Research Board (A.R.R.B.) values are the most representative of actual field situations in Metropolitan Toronto. The A.R.R.B. technique takes into account each individual approach lane, and has specific values tabulated for each lane type and Metro location. The locations are grouped into four classes according to the amount of interference to traffic. The four Metro locations are defined as follows:

Central Business District (CBD) - large numbers of pedestrians, high parking turnover, car and taxi pickups, buses, plus loading and unloading activities.

Industrial (IND) - light industry, warehouses, wharves and other activities. Smaller number of pedestrians than for the CBD, but interference is caused by the loading and unloading of goods, as well as vehicles entering and leaving premises, and low parking turnover.

Residential (RES) - perhaps a store or corner gas station but very few pedestrians. Nearly ideal conditions for free movement of vehicles.

Suburban Shopping (SUB) - characterized by large shopping plazas on the corner. Usually good intersection geometrics, but some interference caused by pedestrian movements related to public transit activities.

Note that it may be necessary to give different classifications to different approaches to one intersection.

Step 1: Initial A.R.R.B. Saturation Flow Values

To estimate the initial saturation flow value for each approach lane, use the tabulated values listed in table 1 based on the location and the lane type.

Table 1: Lane saturation flow values in through-car units per hour of green time (T.C.U./HR GRN):

	Lane Type		
Location	Right & Through	Through	Left & Through
CBD	1270	1580	1550
IND	1570	1700	1670
SUB	1670	1810	1770
RES	1700	1850	1810

Step 2: Public Transit Stop Adjustments

The following equation gives the degree of impact which public transit stops have on the approach capacity to a signalized intersection:

$$Cor = 1 - \left(\frac{B(Ts + 4)}{3600} \times \frac{g}{c}\right)$$

where:

Cor = Correction Factor
B = frequency of public transit (vehicles/hr)
g = effective green time (seconds)
c = cycle length (seconds)
Ts = average stop duration (seconds)

$$\text{if } \frac{OFF}{ON} \geq 2: \quad Ts = 1.5 + 1.0 \times OFF/B$$

$$\text{if } \frac{OFF}{ON} < 2: \quad Ts = 1.5 + 2.0 \times ON/B$$

where:

ON = average hourly passengers boarding

OFF = average hourly passengers alighting public transit vehicles

Note that the above correction factor only applies to transit stops located on the near side of the intersection, since stops located on the far side have a much lower impact on the free flow of traffic, especially if a bus bay is provided.

i) Bus/Trolley Stop Factor:

The initial A.R.R.B. Saturation flow value for the curb lane is multiplied by the correction factor to obtain the adjusted saturation flow value. If the curb lane is a combined right-turn lane/bus bay, then the correction factor should be applied to this lane as outlined in section 5A.

ii) Streetcar Stop Factor:

If the streetcar stop is equipped with a pedestrian island to minimize the effect of passenger loading and unloading on the flow of traffic in adjacent lanes, adjust the initial A.R.R.B. value of the lane the streetcar occupies by the correction factor. If there is no pedestrian island, then the correction factor should be applied to all lanes for the corresponding approach, including an exclusive right-turn lane if one is present. (see section 5A)

Step 3:

Total the lane width, gradient, pedestrian, and parking adjustment percentages, and adjust the saturation flow values accordingly.

3A: Lane Width Adjustment

The saturation flow is directly affected by lane width, and therefore, the tabular values for each lane must be adjusted according to the following table:

Lane Width (ft)	8	9	10-12	13	14	15 or greater
Adjustment (%)	-12	-7	0	+3	+4.5	+6

If an approach width varies but not enough to warrant extra lanes, use the width at the narrowest point within 100 ft of the stopbar. Exit lanes should be at least as wide as the approach lanes. If this is not so, use the width of the exit lanes as the lane width.

If an approach is flared to allow extra lanes, assume that no through vehicle will use a lane which does not continue on the exit side of the intersection. If a lane for through vehicles (shared or through only) either on the approach or exit side is of limited length, treat the case in the same way as if the lane were blocked by a parked vehicle (see step 3D).

3B: Gradient Adjustment

The saturation flow for each lane must also be adjusted for gradient. The Traffic Control Centre (T.C.C.) has established an adjustment factor of +1% per 1% gradient downhill and -1% per 1% gradient uphill, taken as the average within 100 feet of the stopbar.

3C: Pedestrian Adjustment

No special adjustment is made for the effect of pedestrians since the saturation flows in Table 1 are for average conditions within each type of environment. It is suggested that no adjustments be made unless the pedestrian flow is abnormally high for the type of environment.

Where there is a heavy pedestrian flow, it affects right turns much more than through vehicles so it is preferable to increase the tcu equivalent of a right-turning vehicle rather than reduce the saturation flow. This can only be determined through field measurements.

3D: Parking Adjustments

The saturation flow value should be adjusted if parking is permitted along the curb lanes of approach. Although parking is prohibited during all periods on many major roads, and it is illegal to stop in the major direction of travel during the rush hours in Metropolitan Toronto, there are areas where on-street parking is permitted, especially during the offpeak hours of the day. As illustrated in figure 1, a queue of vehicles forms in each approach lane during the red signal until one queue has reached back to the first parked vehicle.

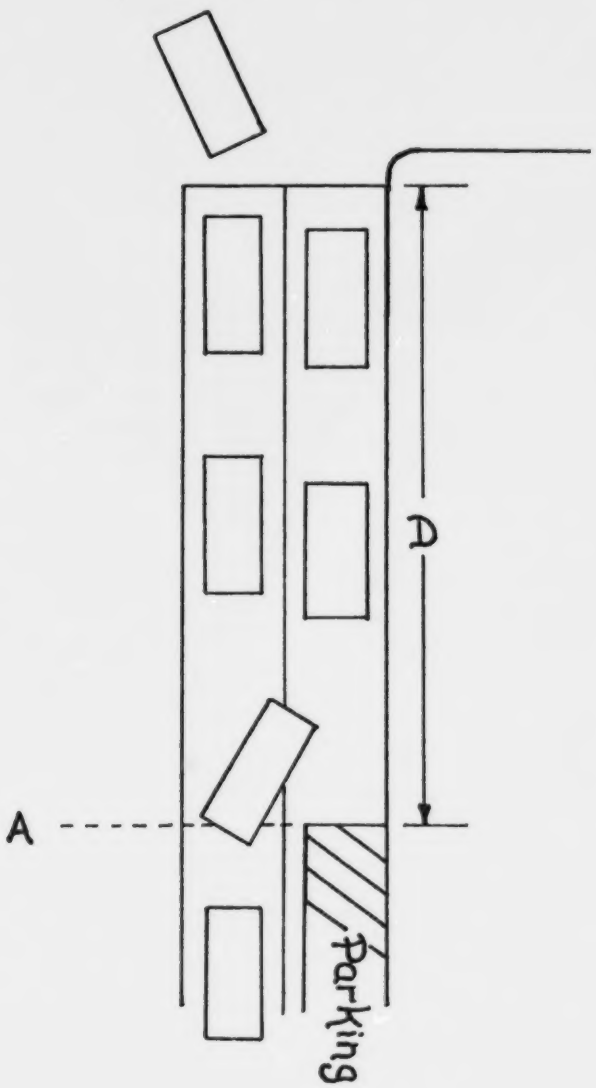


Figure 1.

Often the distance D in the curb lane will not be filled. If possible, D should be great enough to store as many vehicles as can cross the stopbar from the curb lane during one green interval. In Metropolitan Toronto, on-street metered parking spaces range from 17 to 24 feet. This parking distance includes "maneuvering" space which is not present in a queuing situation. Consequently, a distance of L=20 feet will be assigned to each vehicle in the queue.

As outlined in Part II of this Guide, the capacity for the curb lane is given by the formula:

$$C = S_{curb} \times g/c$$

where: C = capacity (pcu/hr or tcu/hr)
S_{curb} = saturation flow (pcu/hr green or tcu/hr green)
g = effective green time (seconds)
c = cycle length (seconds)

Therefore, the required distance D_R is given by:

$$D_R = \frac{S_{curb} g}{c} \times \frac{c}{3600} \times L$$

$$= \frac{S_{curb} g}{180}$$

If the actual distance D_A is less than $\frac{S_{curb} g}{180}$, the saturation flow value used for the curb lane must be reduced to reflect the smaller amount of available storage. If d is the ratio of actual distance D_A to required distance D_R then the saturation flow for the curb lane should be taken as the full saturation flow S_{curb}, for a proportion d of the phase, and as a reduced flow rS_{curb} during the remainder (1-d) of the phase. Therefore, the average saturation flow for the whole phase is given by:

$$\left[d + r\,(1-d) \right] S_{curb} \quad \text{or} \quad W \times S_{curb}$$

The fraction r depends on the percentage of left-turning vehicles on the subject approach, and the ease of execution of left-turns E_{LT}, a detailed description of which is given in Part III of this guide. Tables 2 and 3 give values of r and W respectively.

It must be noted that the above formula only applies to 2 lane approaches where left turns are permitted at the intersection. For locations where left turns are prohibited, those with exclusive left-turn lanes, or for approaches with 3 or more lanes, the following adjustments should be made for parking:

i) During the proportion d of the phase, the total approach saturation flow is given by:

$$S_d = S_{Thru} + S_{curb}$$

ii) During the remainder (1-d) of the phase, the total approach saturation flow is given by:

$$S_{1-d} = S_{Thru}$$

For the whole phase, this yields:

$$S = S_{Thru} + (d)S_{curb}$$

The value S_{Thru} represents the total of the saturation flows for all through and shared left-and-through lanes on the subject approach.

Table 2:

Values of r For Two-Lane Approaches With Parking

		E_{LT}				
		2.0	2.5	3.0	4.0	6.0
% Left Turns	0	0.03	0.03	0.03	0.03	0.03
	10	0.13	0.18	0.22	0.29	0.41
	20	0.22	0.29	0.35	0.45	*
	30	0.29	0.38	0.45	*	*
	40	0.35	*	*	*	*
	50	*	*	*	*	*

* In these cases, the queue of left turns will frequently spread back to reduce the flow at the point A (Fig. 1). In such cases treat the median lane as if it were exclusively for left-turn vehicles.

Table 3:

Values of W for Two-Lane Approaches With Parking

		d						
		.20	.30	.40	.50	.60	.70	.80
r	0.1	0.28	0.37	0.46	0.55	0.64	0.73	0.82
	0.2	0.36	0.44	0.52	0.60	0.68	0.76	0.84
	0.3	0.44	0.51	0.58	0.65	0.72	0.79	0.86
	0.4	0.52	0.58	0.64	0.70	0.76	0.82	0.88
	0.5	0.60	0.65	0.70	0.75	0.80	0.85	0.90

Step 4:

For each approach, total the adjusted saturation flow values. Then apply the following regression equation, developed by the T.C.C. to adjust the Australian Road Research Board's saturation flow values to more closely reflect driving habits within Metropolitan Toronto:

$$\text{Toronto} = 312 + 0.864\ (\text{A.A.R.R.B.})$$

where:

Toronto = the Toronto saturation flow value
A.A.R.R.B. = Adjusted Australian saturation flow value

Step 5:

Saturation values for several lane types not covered by the A.R.R.B. technique were determined by the T.C.C. for Metropolitan Toronto. Unless otherwise specified, there is no need to adjust these formulae for lane width or parking, but adjustments should be made for gradient.

5A: Exclusive Right Turn

i) where an exclusive right-turn lane exists and is controlled by a solid green indication, the following regression equation is used:

$$S = 1073 - 0.21P$$

where: S = saturation flow value (pcu/hr grn)

P = pedestrian volume on the crosswalk through which the right turns must discharge (ped/hr grn)

$$= \frac{\text{Pedestrian volume}}{\text{hour}} \times \frac{\text{cycle length}}{\text{green time}}$$

ii) when the exclusive right-turn lane is controlled by a right-turn green arrow (R.T.G.A.) or a flashing advanced green, a value of S = 1200 (pcu/hr grn) is used, to reflect the higher discharge rate during a "priority movement" type of operation with no pedestrian interference. If a near side bus stop is located in the right-turn lane, the public transit correction factor, COR, described in Step 2 should be applied to the saturation flow value for this lane as follows:

$$S_i = (1073 - 0.21\ P) \times COR$$

$$S_{ii} = 1200 \times COR$$

5B: Unopposed Left Turn

This applies typically to "T" intersections controlled by a solid green indication where there is an exclusive left-turn lane and no opposing volume due to the geometry of the intersection. Here, a saturation value of 1500 pcu/hr grn should be used. For left turns from a one-way street, use the following saturation values:

i) for a shared left-and-through lane, simply use the value from table 1 on page 2 of the Guide.

ii) for an exclusive left-turn lane, use 1500 pcu/hr grn.

For other applications of unopposed left turns from an exclusive left-turn lane, refer to Part 2 of the Guide, entitled "Determination of Capacity:Priority Aspects".

5C: Right-Turn Cutoff

A value of 1200 pcu/hr grn is assumed at all right-turn cutoff facilities with yield control. When analysing this lane type, the ideal case occurs where exclusive approach and discharge lanes exist. However, if there is no storage lane for the right-turning vehicles, the approach will operate as a shared right-and-through lane. The decision as to how the curb lane is to be classified must be made at the discretion of the user.

5D: Shared Left and Right Turns

A value of 1200 pcu/hr grn should be used.

5E: Left or Right-Turn Tunnel

Use a value of 1200 pcu/hr grn.

5F: Double Right Turns

i) For all double-right turn movements in a CBD environment, and for those in other areas which are controlled by a flashing or solid green indication, the following regression equation is used:

$$S = 0.745 \text{ (A.R.R.B.)} + 94.58$$

where A.R.R.B. = 2 x the tabulated value for a shared right-and-through lane. If either of the two lanes need to be corrected for width, the individual corrections should be made for each lane as necessary, then the two values summed, and the gradient correction applied to yield the total A.R.R.B. value.

ii) For double right-turn movements in a non-CBD environment which are controlled by a R.T.G.A. indication, the following equation is used to determine saturation flow:

$$S = 2 \times 1200 \text{ pcu/hr grn}$$

The same corrections for lane width and gradient should be made, if necessary, as indicated in 5Fi, above.

5G: Double Left Turns

i) For intersection approaches that are controlled by a flashing green indication:

$$S = 0.816(\text{A.R.R.B.}) - 15.6 \text{ pcu/hr grn}$$

where A.R.R.B. is the sum of the two A.R.R.B. values for shared left-and-through lanes corrected appropriately for lane width and gradient for each of the respective lanes.

ii) For intersections controlled by a left-turn green-arrow (L.T.G.A.) or a solid green indication, the double-left saturation value is:

$$S = 2 \times 1200 \text{ pcu/hr grn}$$

Note that the above equations in step 5 and assumed values apply directly to Metro Toronto, and must not be corrected again using the Toronto regression equation. Saturation values are estimates only and should never be written in decimal form. Calculated values, whether saturation flows, capacities, or adjusted volumes, should be rounded off to the nearest multiple of five. Do not use rounded values for subsequent calculations, but rather, refer back to the pre-rounded value and round only the final answer. This helps preserve the accuracy of the analysis.

Part II: DETERMINATION OF CAPACITY

As stated previously, the average rate of flow of vehicles is lower both during the first few seconds of green time due to starting delays, and also during the amber period when the motorists must decide whether to stop or proceed through the intersection. The maximum rate of flow or "saturation flow" occurs between these two times or during a span known as the "effective green" period. The remainder of the green plus amber time is referred to as the "lost time". This is a useful concept because capacity is then directly proportional to the effective green time and is given by the formula:

$$C = S \times g/c$$

where C = capacity (tcu/hr or pcu/hr)
S = saturation flow (tcu/hr grn or pcu/hr grn)
g = effective green time (seconds)
c= cycle length (seconds)

Extensive research in Metropolitan Toronto has determined that the time lost at the beginning of green due to start-up delays is balanced by the relatively high utilization of the first few seconds of amber. Therefore, in all calculations, "green" = "effective green".

The exception to the above capacity formula is exclusive left-turn lanes. The capacity of an exclusive left-turn lane is determined with the following method:

1) PRIORITY ASPECTS

a) Flashing and Solid Advanced Green:

$$C_{l_a} = 1500 \text{ pcu per hour} \times \frac{\text{advanced green}}{\text{cycle length}}$$

b) Left-Turn Green Arrows (Permissive):

$$C_{l_b} = 1200 \text{ pcu per hour} \times \frac{\text{green arrow}}{\text{cycle length}}$$

c) Left-Turn Green Arrows (Restrictive):

$$C_{l_c} = 1500 \text{ pcu per hour} \times \frac{\text{green arrow}}{\text{cycle length}}$$

2) GREEN

a) Peak Period Conditions (high opposing volume):

$$C_{2_a} = e^{(-Qt/T)} \times Q \times p$$

where: $e^{(-Qt/T)}$ is the probability that the actual gap will be greater or equal to the required gap.
Q = volume of opposing traffic (tcu/hr). For the purposes of this calculation, the opposing flow should be adjusted based on the following conversions:

i) If opposing right turns are from shared right-and-through lane:
1 right-turning pcu = 1.25 tcu

ii) If opposing right-turns are from an exclusive right-turn lane or a right-turn cutoff:
1 right-turning pcu = 0 tcu

iii) For all opposing left-turning traffic:
1 left-turning pcu = 0 tcu

t= required gap (see Table 4)
T= $\frac{\text{green time (sec)}^*}{\text{cycle length (sec)}}$ x 3600 (sec/hr)
p= the probability of the driver accepting the gap (see Table 4)

* for the opposing traffic

Table 4: Required gap size and probability distribution for left-turn gap acceptance:

No. of Lanes of Opposing Traffic	Required Gap (t)	Probability of Accepting Gap (p)
1	4 sec/pcu	.520
2	5 sec/pcu	.820
3	6 sec/pcu	.950
4	7 sec/pcu	.986

b) Offpeak conditions (low opposing volume):

$C_{2_b} = 1500 \times g/c - Q$ (where g is for the opposing traffic)

where g, c, and Q are as defined above

If $C_{2_b} < 0$, (negative), then $C_2 = C_{2_a}$

If any doubt exists over the definition of "high" versus "low" opposing volume, calculate both C_{2_a} and C_{2_b} and use the larger value.

3) Amber/All Red (Clearance Interval)

$C_3 = 2 \text{ pcu/cycle} \times \frac{3600 \text{ (sec/hr)}}{\text{cycle length (sec)}}$

4) Total Left-Turn Capacity

The total left-turn capacity of an exclusive left-turn lane is the sum of all values from the above sections 1,2, and 3.

Part III: VOLUME/CAPACITY RATIOS

One of the purposes of evaluating the capacity of an approach is to obtain the Volume/Capacity (V/C) ratio. In most instances, this is a very good estimate of the degree of utilization of the potential throughput of an approach to a signalized intersection

The V/C ratios for any exclusive turning movements are evaluated individually, while a single value is calculated for the combination of through and shared lanes.

Volume Conversions

The vehicular volumes for an approach must be adjusted to ensure the V/C ratio will be dimensionless. To accomplish this, a two-stage conversion is used:

1) First, the volumes must be adjusted for composition. This is done using the following equivalents:

   a) 1 commercial vehicle or bus is equivalent to 2 pcu's. These are defined as any vehicle having more than 4 tires in contact with the road.

   b) 1 car or light truck is equivalent to 1 pcu.

At this point the V/C ratio's for any exclusive turning lanes may be calculated as pcu's/pcu.

2) The volumes utilizing shared or exclusive through lanes must then be adjusted further using the following equivalents:

   a) 1 thru pcu is equivalent to 1 tcu

   b) 1 right-turning pcu is equivalent to 1.25 tcu's.

   c) 1 unopposed left-turning pcu is equivalent to 1 tcu, except for left turns from one-way streets. Left turns are then handled in the same way as right turns: equivalent to 1.25 tcu's.

   d) 1 opposed left-turning pcu is equivalent to E_{LT} tcu's.

   where:

$$E_{LT} = \frac{1800}{1500f \times \frac{Sg-Qc}{g(S-Q)} + \frac{3600K}{g}}$$

$$= \frac{1.2}{f \times \frac{Sg-Qc}{g(S-Q)} + \frac{4.8}{g}}$$

where:

f = a function of the opposing flow as given by :

$f = e^{-0.001Q}$ (dimensionless).

Typical values of "f" are given in Table 5.

K = the average number of vehicles which can turn left during the clearance intervals. In Metropolitan Toronto, K = 2 tcu.

1500f = the average number of tcu/hour which can filter through a random flow of Q (tcu/hr).

c = cycle length (sec.)

g = green time (sec.) for opposing traffic.

S = the Toronto saturation flow value for opposing traffic (tcu/hr of grn).

Q = volume of opposing traffic (tcu/hr).

(Note: During a priority indication such as an advanced green, E_{LT}=1.0, since there is no opposing traffic.)

Table #5. Typical values of "f" based on opposing flow:

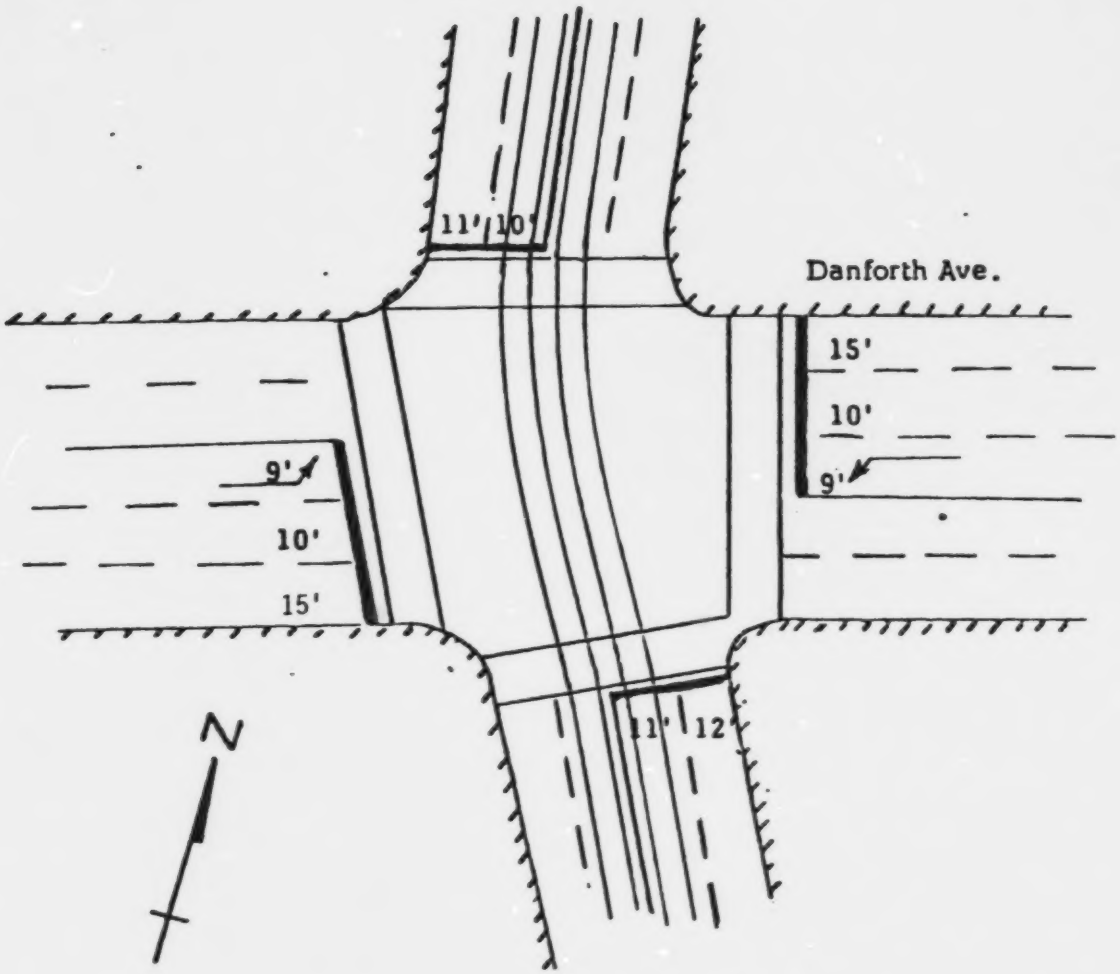
Q (veh/hr)	0	50	100	150	200	250
f	1.00	0.95	.91	.86	.82	.78

300	350	400	450	500	550
.74	.70	.67	.64	.61	.58

600	650	700	750	800
.55	.52	.50	.47	.45

At this point, the V/C ratio for all shared and through lanes may be calculated as tcu's/tcu.

Danforth and Broadview Avenue (Central Business District)



P.M. Signal Timings for Broadview and Danforth

North-South Green	22 Seconds
North-South Amber	4 "
All Red	2 "
Eastbound Flashing Advance Green	7 "
Eastbound Solid Advance Green	2 "
East-West Green	27 "
East-West Amber	4 "
All Red	2 "
Length of Cycle:	70 Seconds

MUNICIPALITY OF METROPOLITAN TORONTO

TRAFFIC ENGINEERING DEPARTMENT

TRAFFIC FLOW DIAGRAM

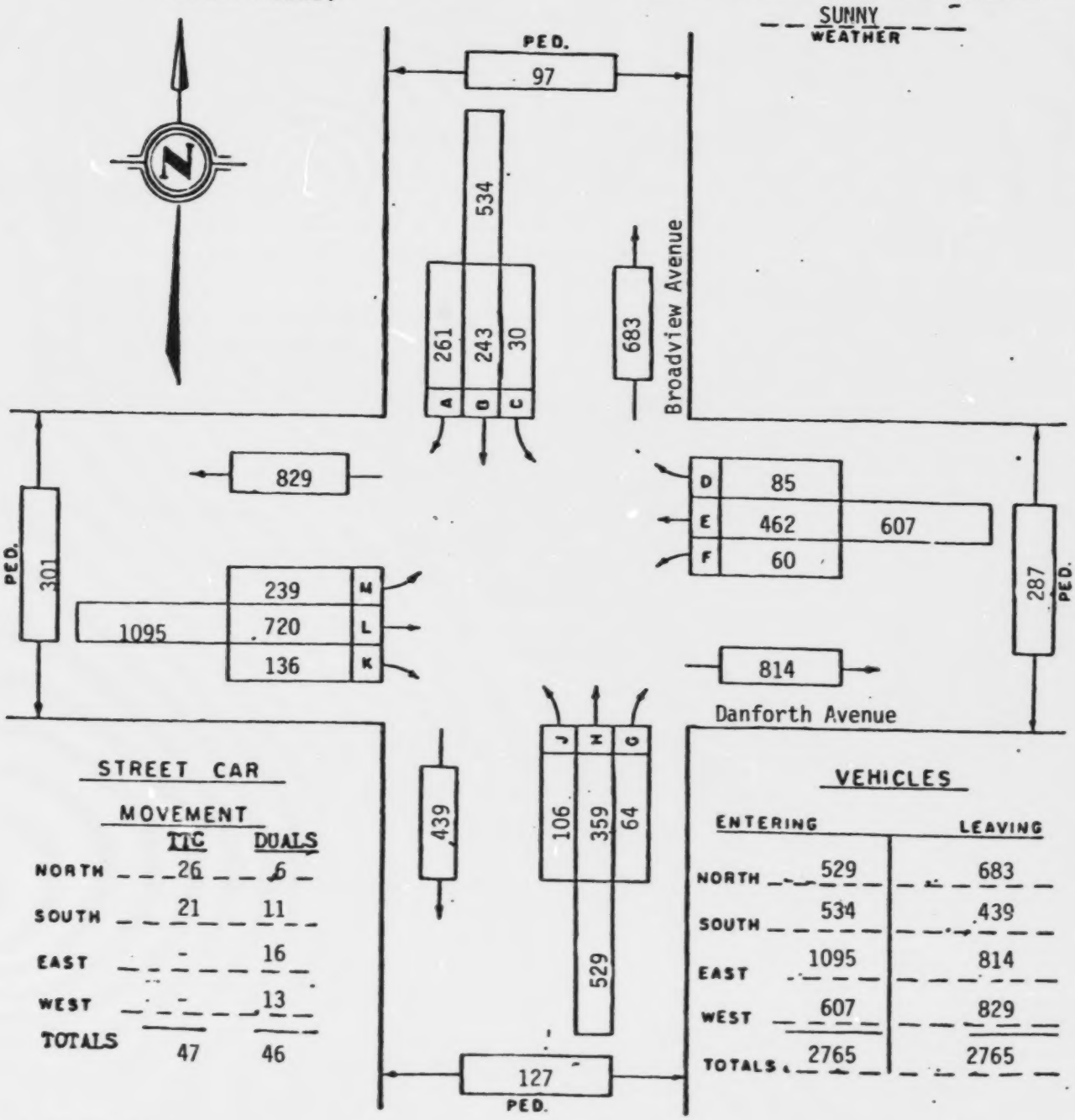
BROADVIEW AVENUE (ROADWAY) AT DANFORTH AVENUE (INTERSECTING ROADWAY)

CITY OF TORONTO (MUNICIPALITY)

JULY 17/79 - THURSDAY (DATE) (DAY)

P.M --- PEAK HOUR (TOTAL HOURS) FROM 4:30P.M TO 5:30 P.M.

SUNNY WEATHER



STREET CAR MOVEMENT

	TTC	DUALS
NORTH	26	6
SOUTH	21	11
EAST	-	16
WEST	-	13
TOTALS	47	46

VEHICLES

	ENTERING	LEAVING
NORTH	529	683
SOUTH	534	439
EAST	1095	814
WEST	607	829
TOTALS	2765	2765

OBSERVATIONS

P.M. PEAK PERIOD

NORTHBOUND APPROACH:

Lane # 1. (12' Right & Thru): 1270 tcu/hr green

Lane # 2. (11' Left & Thru): 1550 tcu/hr green

Total A.R.R.B. Saturation Flow : 2820 tcu/hr green

Public Transit Adjustment:

$B = 26$ streetcars/hr

$ON = 44$ people/hr

$OFF = 65$ people/hr

$\frac{OFF}{ON} = 1.48$

$Ts = 1.5 + 2.0 \times (ON/B)$

$= 4.88$

Cor = 0.98 (No streetcar Island ∴ Adjustment applies to entire approach)

Lane Width Adjustment: None
Gradient Adjustment: 1% Uphill (Correction factor = 0.99)
Parking Adjustment: None

Total Adjusted A.R.R.B. Saturation Flow: $0.99\ (0.98\ (1270 + 1550))$
$= 2736$ tcu/hr green

Toronto Saturation Flow: 2676 tcu/hr green

Northbound Capacity = $\frac{22}{70} \times 2676 = 841$ tcu/hr

Northbound Volume Conversions:

Lefts: (opposing: $Q = 243 + (261 \times 1.25) - 32 + (2 \times 32) = 601$
$g = 22$, $s = 2477$, $f = 0.55$, $c = 70$)

$E_{LT} = 3.13$

$V_{LT} = 106 \times 3.13 = 332$ tcu/hr

Thru: $V = 359 - 32 + (2 \times 32) = 391$ tcu/hr

Rights: $V = 64 \times 1.25 = 80$ tcu/hr

Northbound Approach V/C = $(391 + 80 + 332) / 841 = 0.95$

SOUTHBOUND APPROACH:

Although no parking is permitted on this approach during the P.M. peak, for illustrative purposes assume that parking is permitted 120 feet back from the stopbar. Since the volume conversions are required for input to the E_{LT} calculation which is necessary for the determination of the parking correction, the volume conversion calculations will be done first.

Southbound Volume Conversions:

Lefts: (opposing flow) $Q = 359 + (64 \times 1.25) - 32 + (2 \times 32) = 471$
$g = 22$, $s = 2676$, $f = 0.63$, $c = 70$

$E_{LT} = 2.16$

$V_{LT} = 30 \times 2.16 = 65$ tcu/hr

Thru: $V_T = 243 - 32 + (2 \times 32) = 275$ tcu/hr

Right: $V_{RT} = 261 \times 1.25 = 326$ tcu/hr

Total Southbound Approach Volume
$V = 666$ tcu/hr

Southbound Approach:

Lane #1. (11' Right and Thru): 1270 tcu/hr green

Lane #2. (10' Left and Thru): 1550 tcu/hr green

Public Transit Adjustment:

$B = 21$ streetcars/hr

$ON = 32$ people/hr

$OFF = 29$ people/hr

$\frac{OFF}{ON} = 0.91$

$Ts = 1.5 + (2.0 \times \frac{ON}{B})$

$= 4.55$

$$Cor = 1 - \left(\frac{21\ (4.55 + 4)}{3600}\ \frac{22}{70}\right)$$

= 0.98 (No streetcar island; therefore adjustment applies to entire approach)

Lane Width Adjustment: None
Gradient Adjustment: None
Parking Adjustment: Percentage left-turns = $\frac{30}{534} = 0.056$

Refer to Table 2 and determine value of r by interpolation:

$$E_{LT} = 2.0: \frac{0.13 - 0.03}{\left(\frac{10 - 0}{100}\right)} \times (0.056 - 0.0) + 0.03 = 0.086$$

SOUTHBOUND APPROACH (CONT'D)

$$E_{L_T} = 2.5 : \frac{0.18 - 0.03}{\left(\frac{10 - 0}{100}\right)} \times (0.056-0.0) + 0.03 = 0.114$$

$$E_{L_T} = 2.16 : \frac{0.114 - 0.086}{2.5 - 2.9} \times (2.16 - 2.0)+0.086=0.095$$

therefore $r = 0.095$

r must be rounded up to 0.10 because
Table 3 is not valid for r less than 0.10

$D_A = 120$ ft.

$$D_R = \frac{S_{curb}g}{180} = \frac{(1270)(22)}{180} = 155 \text{ ft}$$

$$d = \frac{D_A}{D_R} = 0.77$$

Using Table 3, determine W by interpolation

$$W = \left(\frac{0.82 - 0.73}{0.80 - 0.70}\right)(0.77 - 0.70) + 0.73$$

$W = 0.793$

Therefore the curb lane saturation flow is reduced to 0.793 x Scurb due to the effect of parking.

The A.A.R.R.B. approach saturation flow becomes:

$$S = (1550 + 0.793 \times 1270) \times 0.98$$
$$= 2506 \text{ tcu/hr grn}$$

The Toronto saturation flow is 2477 tcu/hr grn

$$C = S \times \frac{g}{c} = 778 \text{ tcu/hr.}$$

$$\frac{V}{C} = \frac{666}{778} = 0.86$$

EASTBOUND APPROACH:

Lane #1. (15' Right & Thru): 1270 tcu/hr green
Lane #2. (10' Thru) : 1580 tcu/hr green
Lane #3. (9' Excl. Left) : see below

Total A.R.R.B. Saturation Flow : 2850 tcu/hr green
Public Transit Adjustment : None
Lane Width Adjustment : Lane # 1 = +6%
Gradient Adjustment : None
Parking Adjustment : None

Total Adjusted A.R.R.B. Saturation Flow = 1270 x 1.06 + 1580
= 2925 tcu/hr green

Toronto Saturation Flow: = 2839 tcu/hr green
Eastbound Capacity = $\frac{36}{70}$ x 2839 = 1460 tcu/hr

Left-turn Capacity:
Advance Green: C_{1_a} = 1500 x $\frac{9}{70}$ = 193 pcu/hr
Green: Q = 581 tcu/hr, T = $\frac{27}{70}$ x 3600 = 1389
t = 5 sec
p = 0.820
C_{2_a} = 59 pcu/hr
Amber/All Red C_3 = 2 x $\frac{3600}{70}$ = 103

Total Left-turn Capacity : = $C_{1_a} + C_{2_a} + C_3$
= 355 pcu/hr

Eastbound Volume Conversions:

Lefts: V = 239 pcu
Thru : V = 720 - 16 + (16x2) = 736 tcu
Rights: V = 136 x 1.25 = 170 tcu

Eastbound Approach V/C: = (736 + 170) tcu/1460 tcu = 0.62

Left-turn V/C: = 239/355 = 0.67

WESTBOUND APPROACH:

Lane #1. (15' Right & Thru): 1270 tcu/hr green
Lane #2. (10' Thru) : 1580 tcu/hr green
Lane #3. (9' Excl. Left) : see below

Total A.R.R.B. Saturation Flow : 2850 tcu/hr green

Public Transit Adjustment : None
Lane Width Adjustment : Lane #1 = +6%
Gradient Adjustment : None
Parking Adjustment : Although no parking is permitted on this approach during the P.M. peak, for illustrative purposes assume parking is allowed 100 feet from the stopbar.

D_A = 100 ft.

$D_R = \frac{(1270)(1.06)(27)}{180}$ = 202 ft

d = 0.50

A.R.R.B saturation flow:

S = (1270)(1.06)(0.50) + 1580

S = 2253 tcu/hr grn

Toronto saturation flow: 2258 tcu/hr grn

Westbound Approach Capacity:

$C = 2258 \times \frac{27}{70} = 871$ tcu/hr

Left Turn Capacity: Q = 890 - 16 + (2x16) = 906

$T = \frac{36}{70} \times 3600 = 1851$

t = 5 sec, p = 0.820

C_{2_a} = 64 pcu/hr

Amber/All Red : $C_3 = 2 \times \frac{3600}{70} = 103$ pcu/hr

Total Left-Turn Capacity: $= C_{2_a} + C_3$
= 167 pcu/hr

Westbound Volume Conversions:

Lefts: 60 pcu
Thru: 462 - 13 + (2x13) = 475 tcu
Rights: 85 x 1.25 = 106 tcu

WESTBOUND APPROACH (CONT'D)

Westbound Approach V/C = (475 + 106)/ 871 = 0.67

Left-turn V/C = 60/ 167 = 0.36

PART V BALANCING V/C RATIOS AND DETERMINING RESERVE CAPACITY

Using the previous worked example of Broadview and Danforth, the following technique outlines the methodology for redesigning the existing signal timing at an intersection once the V/C ratios have been determined.

STEP 1: Consider only the through and shared movements on each approach, and take the larger of the two V/C's for each of the simultaneous movements:

A) The northbound V/C of 0.95 is larger than the southbound V/C of 0.86.

B) The westbound shared right-and-through V/C of 0.67 is larger than the corresponding eastbound value of 0.62.

Therefore, use the V/C's from the northbound and westbound approaches for balancing.

STEP 2: Determine the desired V/C ratio for these two approaches:

$$\begin{aligned} \text{northbound} &= 0.95 \\ \text{westbound} &= \underline{0.67} \\ \text{total} &= 1.62 \end{aligned}$$

Therefore the balanced $V/C = \frac{1.62}{2} = 0.81$

STEP 3: Determine the capacity required on the respective approaches to attain this new V/C:

A) Northbound: $V/C = 0.81$, $V = 803$

Therefore: $C = \frac{V}{0.81} = \frac{803}{0.81} = 991$ tcu/hr

B) Westbound: $V/C = 0.81$, $V = 581$

Therefore: $C = \frac{V}{0.81} = \frac{581}{0.81} = 717$ tcu/hr

STEP 4: Determine the green time required on the respective approaches to attain the new capacity:

A) Northbound: $C = S \times g/c$

where $S = 2676$ tcu/hr grn

cycle = 70 seconds

Therefore: $g = \frac{C \times c}{S}$

$= \frac{991 \times 70}{2676}$

$= 25.9$ seconds

(round up to 26 seconds)

B) Westbound: $C = S \times g/c$
where S = 2258
cycle = 70 seconds

Therefore: $g = \frac{C \times c}{S}$
$= \frac{717 \times 70}{2258}$
= 22.2 seconds
(round up to 23 seconds)

The revised signal timing for Broadview and Danforth during the P.M. peak with the V/C ratios "balanced" is:

North-South Green	26 Seconds
North-South Amber	4 "
All Red	2 "
Eastbound Flashing Advance Green	7 "
Eastbound Solid Advance Green	2 "
East-West Green	23 "
East-West Amber	4 "
All Red	2 "
Length of Cycle:	70 Seconds

STEP 5: Determine the resulting V/C ratios for the other movements, given the new signal timing:

A) Southbound: S = 2477 tcu/hr grn

Therefore: $C = S \times g/c$
$= 2477 \times \frac{26}{70} = 920$ tcu/hr
V = 666 tcu/hr

Therefore: $V/C = \frac{666}{920} = 0.72$

B) Eastbound (thru and right):
S = 2839 tcu/hr grn

Therefore: $C = 2839 \times \frac{32}{70}$
= 1298 tcu/hr
V = 906 tcu/hr

Therefore: $V/C = \frac{906}{1298} = 0.70$

Eastbound (lefts):
Q = 581 tcu/hr t = 5 sec/pcu
T = 1183 p = 0.82

Therefore: C_{2a} = 41 pcu/hr

From the worked example: C_{1_a} = 193 pcu/hr

Therefore: C_{left} = 337 pcu/hr
$V/C = \frac{239}{337} = 0.71$

C) Westbound (lefts):
Q = 906 tcu/hr T = 1646
t = 5 sec/pcu p = 0.82

Therefore: C_{2_a} = 47 pcu/hr

From the worked example: C_3 = 103 pcu/hr

Therefore: C_{left} = 150 pcu/hr
$V/C = \frac{60}{150} = 0.40$

The signal timing for this intersection is now considered "optimum" for the given conditions. To determine the amount of "reserve" capacity, or the number of additional vehicles which can be accommodated at this intersection, the following calculations should be made:

1) The maximum design value which should be used for any V/C ratio is 0.90. This provides a "cushion" for the peaking characteristics inherent in a typical traffic stream, and also allows for any error in estimating future traffic volumes.

2) Using the previous example of balancing as a basis for determining reserve capacity:

A) Northbound: $V/C_{maximum}$ = 0.90

From Step 3A: C = 991 tcu/hr V = 780 tcu/hr

Therefore: V = 0.90 x 991 tcu/hr
= 892 tcu/hr

Therefore reserve capacity = 892 - 780 = 112 tcu/hr

Since this value represents through-car units, any proposed development which results in additional left or right-turn volumes requires that these movements be adjusted using the equivalent left-turn (E_{LT}) formula or the right-turn equivalency factor of 1.25 respectively. In addition, the V/C ratio for the southbound approach should be recalculated to reflect the higher northbound volume which will directly affect the E_{LT} value for southbound left-turns. It is for this reason that reserve capacity can only be determined for single approaches, and not for an entire intersection, unless a lengthy series of calculations are made to determine the impact of higher opposing volumes on left-turn V/C ratios. This may then require further balancing of the higher V/C's to reduce them below 0.90 if necessary.

PART VI: LIST OF VARIABLES USED IN THIS GUIDE

B -Frequency of public transit vehicles (veh/hr)

C -Capacity (tcu/hr or pcu/hr): maximum throughput of a lane or approach per hr.

c -Cycle length (sec)

Cor -Correction factor for Public Transit stops

D_A -Actual distance (ft) from the stop bar to the first parked vehicle on an approach where parking is permitted

D_R -Recommended distance (ft) from the stop bar to the first parked vehicle. It is the space required to store as many vehicles as could cross the stop bar from the curb lane during one green interval.

d -Distance ratio (dimensionless): D_A/D_R

e -Base of the natural logarithms (2.71828...)

E_{LT} -Equivalent left-turn factor (dimensionless) used to convert left-turn volume from a shared left-and-through lane into equivalent tcu's.

f -Function of opposing traffic (dimensionless) given by $f=e^{-0.001Q}$

g -Green time (sec) allotted to a given approach

K -Clearance value (veh): the average number of vehicles that can clear during one clearance interval (K=2 for Toronto)

L -Length (ft) of roadway assigned to an average vehicle in a queue. (in Toronto, L=20')

OFF -Average hourly number of passengers alighting transit vehicles (passengers)

ON -Average hourly number of passengers boarding transit vehicles (passengers)

P -Pedestrian volume (ped/hr grn) that interferes with a right-vehicular movement from an exclusive turn lane

p -Probability of a left-turning motorist accepting a gap of t seconds in duration in the opposing flow

pcu -Passenger car unit: a car or small truck having not more than four (4) tires on the road

Q -Volume of traffic opposing or impeding the flow of a left-turn movement (tcu/hr)

r -Reduction factor for the curb lane saturation flow for that portion of the phase during which parked vehicles have an effect

S -Saturation flow (tcu/hr or pcu/hr): the maximum rate at which vehicles could cross the stop bar if there was a continuous queue and they were given 100 per cent green time

T -Green time per hour (sec/hr) during which the opposing traffic (Q) can discharge through an intersection

Ts -Transit stop time (sec): average stop time of a public transit vehicle

t -Gap time (sec): the required duration of a gap in the opposing flow necessary for a left-turn to be executed

tcu -Through car unit: a passenger car unit which passes straight through an intersection, or if it executes a turn from a shared lane, the appropriate correction factor is applied to convert it to a tcu

V -Volume (tcu/hr or pcu/hr) of traffic travelling in the direction under study

W -The expression (dimensionless) for the curb-lane saturation flow for an entire phase during a portion of which parking has some influence

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David B. Richardson, P. Eng.
August 9, 1982

B.2 DESIGN SPEED (prepared by J. Lam)

Design speed may be defined as the average speed of travel which a vehicle could maintain between two successive stop bars on a specified arterial, assuming that no delays are accrued due to the presence of signal controls at intersections. Implicitly, the design speed does include the effect of such factors as intensity of land use, parking regulations, mid-block pedestrian cross-walks, bus stops, traffic volume and traffic composition.

Although design speed is an important parameter in signal co-ordination design, there exists no theoretical method by which the design speed for a given link can be calculated based on a set of given conditions. Most methods available to date are either arbitrary or empirical in nature. The following are descriptions of methods which have been employed in Toronto with reasonable results.

The ideal speed may be obtained from the arterial speed limit. A general guideline is a 'speed limit minus five miles per hour' relationship with special consideration given to free-flowing or severely congested links. This method is comparatively simple to use and does provide an optimistic speed which the program can attempt to achieve through offset design. The problem with this technique however, is that not all links operate at the same level of service during different periods of the day. Therefore some over-estimation of design speed may result in areas of heavy congestion, while free flowing links will be underdesigned.

Since this technique is somewhat subjective, it is suggested that the user consider the following factors which are listed in order of importance, so that the design speed values can be adjusted according to link characteristics:

a) Speed limit

b) Volume per effective lane

c) Link length

d) Presence of pedestrian crosswalks and number of link

e) Number of access and egress points on the link

f) Presence of transit stops on the link and general transit activity

g) Geometric aspects including horizontal and vertical alignment, lane width, number of lanes, and presence of medians, islands and exclusive turn lanes

h) General operational aspects including general pedestrian activity, general parking activity, percentage trucks, and surrounding land use type.

To overcome the inherent inconsistencies with this technique, and analytical tool has been developed which calculates four different average speeds for individual links based on arterial speed and delay information. The four cases are as follows:

a) Free speed #1 - the average speed when no stops occurred.

b) Free speed #2 - the average speed with the delay time due to signal stops deleted.

c) Average speed including the delay time associated with all 'other' stops.

d) Overall weighted average of cases a, b and c or what is herein referred to as 'global speed'

A number of statistics are calculated along with each case for the individual operational time periods (OTP's):

a) Number of samples rejected - upper and lower limits were placed on the individual link speeds to eliminate obviously bad data as follows:

i) Central networks: 3 MPH (5 KPH) < Acceptable Speed < 40 MPH (65 KPH)

ii) Suburban networks: 3 MPH (5 KPH) < Acceptable Speed < 50 MPH (85 KPH)

b) Number of samples accepted - the sample size used for all subsequent calculations.

c) Standard Deviation.

d) Confidence Limits - a 95% significance level is used to obtain the best of the four average speeds depending on which has the smallest confidence limits.

e) High speed - the highest average speed obtained on that link (subject to the quality control limits in (a)).

f) Low speed - same as (e).

In the majority of cases, the global speed is the most statistically significant value mainly due to the sample size. In the remainder of cases the 'no stop' average may be selected as the most representative of the ideal speed on a particular link. The justification for the choice of speeds is as follows:

a) The 'free speed 1' represents the true free speed on the particular link under investigation since no stops occurred and free flow conditions prevail.

b) The 'free speed 2' is a good approximation of free speed since the delay time associated the signal stops is eliminated. The reason for this is that under ideal conditions, no signal stops should occur along the link if the design speed and offset relationship is correct. In fact this would provide the true design speed estimate.

c) Other stops along a link are normally inherent characteristics of that particular sections of roadway

and thus are effectively 'built into' the design speed of the link.

d) Global speed was found to be the best overall value to use in the majority of cases since the sample size resulted in a more statistically significant figure for each link. It incorporates all of cases a to c and thereby can be used wherever speed and delay information has been gathered for a particular arterial or network signal system as a basis for offset design.

(Readers may also refer to reference 13 for an alternate approach to design speed calculation)

B.3 PLATOON DISPERSION FACTOR (prepared by J. Lam)

The design of signal coordination patterns for arterials and networks is traditionally based on the premise that vehicles travel between signals with the same speed and with constant headways. In reality, however, as a traffic platoon moves downstream from a signal, vehicles in the platoon will attain different speeds due to different vehicle characteristics, driver behaviour, lane-to-lane road conditions, and interference from pedestrians, roadside activities and side-street traffic. As a result, platoon dispersion occurs, distorting the arrival pattern at the downstream signal. Neglecting the effect of this phenomenon would reduce the effectiveness of the signal coordination design. However, there has been increasing recognition of the importance of platoon dispersion in traffic signal control practice. Allowance for platoon dispersion is made in previously developed signal design programs such as TRANSYT and the GLC-Combination Program. Similar allowance is also made in SSTOP.

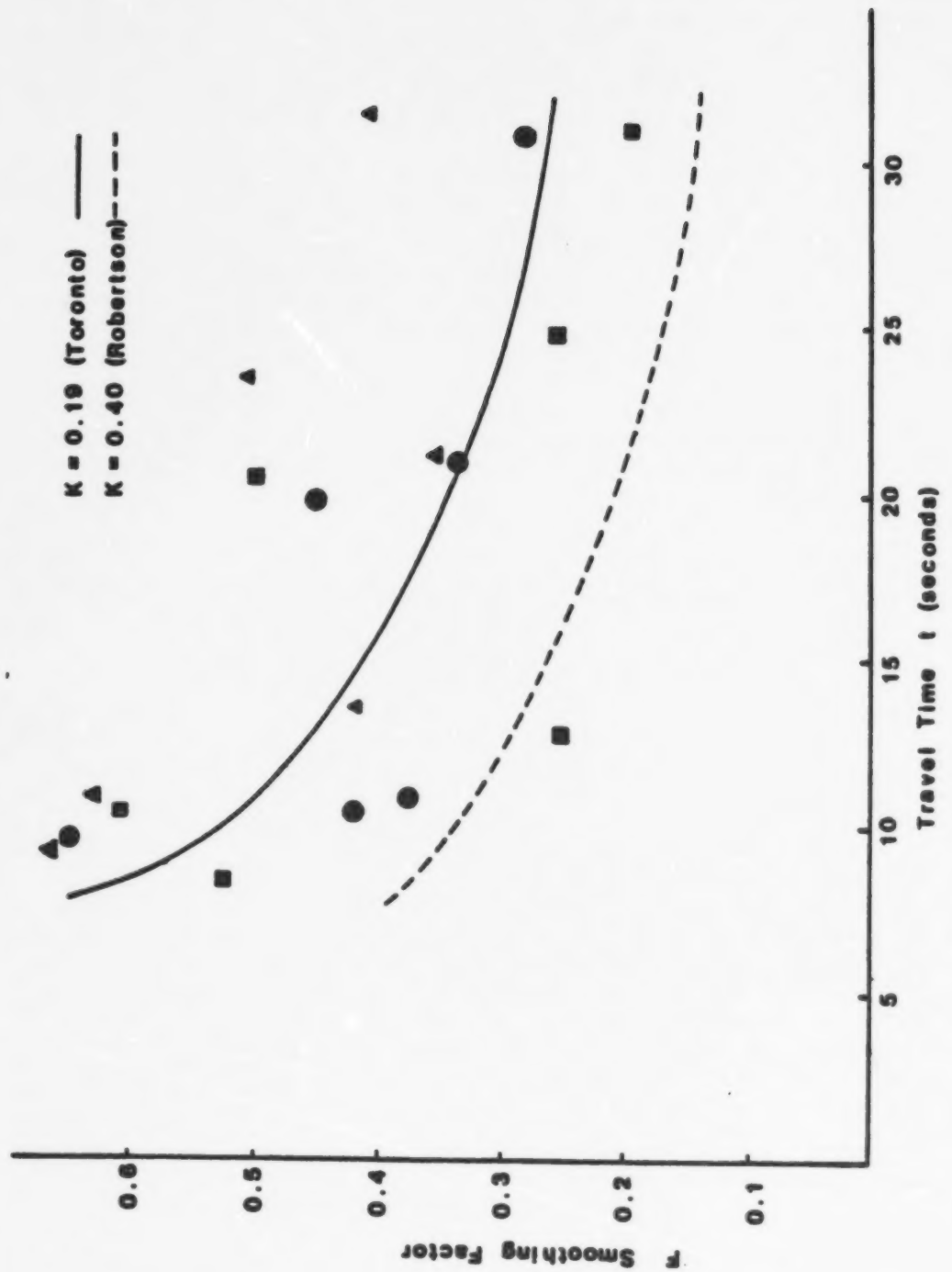


Figure B.2 - Relationship Between Smoothing Factor and Travel Time

B.3.1 Robertson's Platoon Dispersion Model [5]

The platoon dispersion model in the afore-mentioned programs was originally developed by Robertson who uses an empirical equation to predict the downstream arrival pattern at the end of a link given the upstream traffic pattern. The model's ability in accurately describing traffic flows between signals has contributed greatly to the effectiveness of the above signal optimization programs.

A number of years ago, field studies were conducted in Toronto to validate the Robertson model for local conditions. It was found that the accuracy of the model could be significantly improved by the introduction of a number of modifications. The impact of these modifications on offset design and performance evaluation was analyzed and found to be significant. As a result of the improvements, the choice of offset for given link may be shifted by 4 to 6 seconds with delay savings of up to 20%.

The above research findings led to the development of a Modified Robertson Model which is incorporated in the SSTOP Program. The modified model is described in Section C.3.4.

B.3.2 Model Calibration

In modifying the Robertson model, much of the improvement is brought about by the calibration of the model for locally prevalent conditions. As indicated in Appendix C, the Robertson platoon prediction equation uses a smoothing factor F given by:

$$F = \frac{1}{1 + Kt}$$

where t = travel time
K = a model parameter

Robertson suggests a value of 0.40 for K but admits that K may vary according to site characteristics. It was established in the Toronto study that a K value of 0.40 is reasonable for downtown conditions, but an average K value of 0.19 is more appropriate for suburban locations. These two respective values are recommended to SSTOP users, although an average value of 0.25 is used as a default parameter for SSTOP. Preferred values may be entered on Card Type 5. Figure B.2 shows the relationship between the smoothing factor and travel time for a suburban arterial. The curve representing the measured values is similar to the Robertson curve but the significant shift in position indicated a change in the K parameter, thus demonstrating the need for calibration.

For those interested in calibrating the model instead of adopting the recommended values, the following calibration procedure can be used:

a) Measure the flow leaving the upstream intersection of the link in question in 5-second intervals using a method similar to saturation flow measurements. (Section B.1.4)

b) Similarly, measure the arrival rate downstream at a point far enough upstream such that the flow rate is not affected by any queueing at the downstream signal.

c) Construct flow histograms for both the upstream and downstream flow patterns.

d) Apply the Robertson equation on the upstream histogram to predict downstream patterns using different K and corresponding F values. By trial and error, the F factor giving the best fit with the actual downstream pattern can be found.

e) The above procedure may be repeated for different links and for different control periods.

This calibration process can be very tedious if followed manually. Efforts can be reduced by use of a computer program.

B.3.3 Feasibility of Coordination

Another important aspect of platoon dispersion is the degree of platoon dispersion and its relationship with the feasibility of synchronization. If along a particular link the platoon is completely broken down as it arrives downstream and the arrival pattern becomes uniformly distributed over the entire cycle length, little or no benefit can be derived from signal coordination. It will then be beneficial to omit the link in question from the coordination design. This could mean significant savings in computer process time and coding efforts. Moreover, link omissions reduce the number of constraints on the offset optimization process and a higher degree of optimization will result for the rest of the signal network.

APPENDIX C - DETAILED DESCRIPTION OF SSTOP ALGORITHM
(adapted from Reference 3)

C.1 INTRODUCTION

The SSTOP package is designed to compute, offline, optimal signal timing parameters (cycle lengths, offsets and splits) for signal networks, based upon a given set of input parameters. This package was essentially a restructuring of the Real-Time Optimization Program (RTOP) as developed by staff of the Metropolitan Toronto Roads and Traffic Department under contract to the Transportation Development Agency of Transport Canada and the Ontario Ministry of Transportation and Communications. The revised program may now be used by all traffic engineers having access to a computer or computer terminal.

The algorithm is in essence a modular set of programs written in FORTRAN thus enabling any one of its elements or subroutines to be easily modified. Developed from a base of existing traffic control and signal timing theories which have previously been tested in terms of their effectiveness and practicability in previous research efforts, the specific elements are described in the following paragraphs.

C.2 Signal Timing Computation for Individual Traffic Signals

C.2.1 Volume-Saturation Flow Computations

Given the network input data the SPRITS subroutine calculates the volume-saturation flow ratios for each signalized intersection approach. To illustrate this procedure, two examples are considered (i.e. a simple two phase signal and a split phase signal arrangement).

C.2.1.1 Simple Two-Phase Signal

Considering a simple two-phase, four-legged intersection, the volume-saturation flow ratios (Y) of the various approaches are:

$$Y_1 = V_1/S_1 \text{ , } Y_3 = V_3/S_3 \text{ for the north-south phase}$$

$$Y_2 = V_2/S_2 \text{ , } Y_4 = V_4/S_4 \text{ for the east-west phase}$$

where V = approach volume, provided as program input
S = saturation flow, provided as program input

The greater Y ratio for each phase is then identified as

$$Y_n = MAX \{Y_1, Y_3\}$$

$$Y_e = MAX \{Y_2, Y_4\}$$

where Y_n = critical Y ratio for the north-south phase
Y_e = critical Y ratio for the east-west phase

While the above example is applicable to a two phase signal, it may be extended to deal with multi-phase operations.

C.2.1.2 Split-Phase Signal

It is quite common in signal timing design to provide for split-phase arrangements which accommodate heavy turning movements on a separate signal indication such as a flashing advanced green, delayed green or back-to-back left-turn arrows. In the cases of a flashing advanced green or delayed green, the problem becomes one of identifying the critical Y ratios since the priority green indication is commonly shared by the left-turn and through movements facing it. The through movement also shares the right-of-way with the opposing flow during the subsequent or preceeding major solid green indication. For this reason, a special procedure is used in the SPRITS subroutine for calculating Y ratios at intersections with advanced or delayed greens. It is also recognized that the through movement is also active during the clearance interval separating the two green indications. Since the number of vehicles cleared during this clearance interval cannot be established a priori, the current version of SSTOP assumes this value to be zero for purposes of cycle length calculations. Hence it is possible that the cycle time requirements for intersections having split phases may be overestimated.

To illustrate the operation of SSTOP, a simple two-phase, four-legged signalized intersection with a northbound advanced green has been assumed. The volumes and saturation flows of the various approaches are denoted with the appropriate subscript. According to the coding convention within the program, negative subscripts are used for the advanced left-turn movement and positive subscripts for delayed greens. The signal phasing is divided into three green intervals.

If the northbound through movement is critical in terms of the volume-to-saturation flow ratio, the signal can be treated as having two green intervals. However, if the northbound left turn and the southbound flows combined are critical, then the signal should be treated as a three green interval signal.

The volume-to-saturation flow (Y) ratios of all the individual traffic movements are calculated as follows:

(i) For the east-west phase,

$$Y_2 = \frac{V_2}{S_4}, \quad Y_2 = \frac{V_4}{S_4}$$

(ii) For the north-south phase,

$$Y_1 = \frac{V_1}{S_1}$$

$$Y_3 = \frac{V_3}{S_3}$$

$$Y_{-3} = \frac{(V_{-3} - K)}{S_{-3}}$$

In calculating Y_3, the northbound through movement is considered, and the priority green and through green are combined as one interval. In the case of the northbound left-turn movement, it is first assumed that the through green and clearance intervals provide a capacity of up to K vehicles per hour. The default value for K is 100, but may be user-specified on optional card types. The remaining left-turn volume is then cleared during the priority green interval with an appropriate saturation flow (S_{-3}).

The critical Y-ratio for each phase is determined by the following procedure:

(i) For the east-west phase,

$$Y_e = \text{MAX}\{Y_2, Y_4\}$$

(ii) For the north-south phase, an inequality test is made; if $Y_1+Y_{-3}<Y_3$, then the northbound left-turn and its opposing flows are critical with ratios Y_n and Y_{-n}

respectively given by:

$$Y_n = Y_1$$

$$Y_{-n} = Y_{-3}$$

In this case the signal can be treated as having three green intervals. If $Y_1+Y_{-3}<Y_3$, then the northbound through movement is critical. This signal can be regarded as a simple two-phase case. To maintain a three interval design for programming consistency and simplicity, Y_1 is adjusted to the critical Y_3 ratio and this is then used as the critical ratio Y_n for an for an equivalent three-interval operation.

That is:

$$Y_n = Y_3 - Y_{-3}$$

$$Y_{-n} = Y_{-3}$$

The program can handle up to six green intervals with a maximum number of eight through and eight left-turn approach links.

C.2.2 Cycle Length Computations

The next step in the SPRITS subroutine is the computation of a number of candidate cycle lengths for each signal in the network based on different design criteria.

C.2.2.1 Absolute minimum cycle length

The cycle length to be used by any signal must not be less than the aggregate of its minimum requirements such as minimum pedestrian walk time. The absolute minimum cycle C_A is given by:

$$C_A = \sum_{i=1}^{n} (W_i + L_i)$$

where W_i = minimum green based on pedestrian walk time or vehicular requirements, for the ith phase.
L_i = total lost time for the either phase including losses during the start of green and during the clearance intervals.
n = number of phases.

The values of C_A set the lower limit of any candidate cycle length.

C.2.2.2 Webster's cycle calculations

Two different cycle lengths are calculated based on Webster's Method {4} to satisfy the capacity constraints. The minimum cycle length to provide adequate capacity is given by:

$$C_w = \frac{\sum_{i=1}^{n} L_i}{1 - \sum_{i=1}^{n} Y_i}$$

where L_i = total lost time for the ith phase.

Y_i = critical y-ratio for the ith phase.

n = number of phases.

As an example, for the case depicted in Figure A.3,

$$\sum_{i=1}^{n} Y_i = Y_i + Y_{-n} + Y_e \quad .$$

If the sum of the critical Y ratios exceeds 1.0, an error message is printed (Section E.1.21) and the program terminated. While the value of C_w would satisfy the minimum capacity requirements, a more practical cycle length would be obtained if the volume-to-capacity ratio or saturation ratio is set at 0.9. When the saturation ratio is beyond 0.9, the resulting signal setting would not be efficient in coping with cycle-to-cycle traffic fluctuations, and vehicular delays tend to increase sharply. With 90% utilization of the signal capacity, the cycle length C' is given by:

$$C'_w = (0.9 \sum_{i=1}^{n} L_i)/(0.9 - \sum_{i=1}^{n} Y_i)$$

If the sum of the critical Y ratios is greater than 0.9, C'_w is set to C_w. Whenever possible, the use of C'_w is preferred. However, C_w provides a back-up cycle length value which can be tolerated for the benefit of system coordination.

C.2.2.3 Minimum green cycle lengths

The Webster Method for cycle length calculation assumes that after the calculated cycle is chosen, the green times for the various phases can be proportioned according to their respective volume-to-saturation flow ratios. By doing so, equal degrees of saturation are maintained for all critical approaches. However, this may not always be possible in practice. If the minimum green requirement for pedestrians exceeds the actual vehicular requirement, the share of green time among the various phases will be distorted, and this could possibly create a capacity problem. As an illustration, consider an intersection between a major arterial and minor residential street. Suppose that the major flow warrants 80% of the total green time, but the side street requires 40% of the green to satisfy the pedestrian crossing time requirement. Then, only 60% of the total green time can be allocated to the major direction, thus creating a capacity deficiency. To avoid this situation, two other candidate cycle lengths are calculated for each intersection using the procedure outlined below.

First of all, the lengths of each of the green intervals is calculated in proportion to their respective volume-to-saturation flow ratios using the cycle length C_w previously calculated. The green times thus calculated are compared to the minimum walk time requirements. All intervals having a calculated green time less than the required walk time are identified. The interval with the largest walk time/volume-to-saturation flow ratio is most likely to cause timing problems. The ratio is expressed by:

$$\frac{W_i}{Y_i}$$

where W_i = minimum green for the ith phase.
Y_i = critical y-ratio for the ith phase.

The phase creating the problem is identified by:

$$\frac{W_p}{Y_p} = \max \frac{W_n}{Y_n}, \frac{W_e}{Y_e}, \frac{W_s}{Y_s}, \frac{W_w}{Y_w}$$

where the subscript p denotes the problem phase, and the subscripts 'n', 'e', 's', and 'w' denote the north, east, south, and west phases respectively.

Two new candidate cycle lengths (C_p , C'_p) are then computed as follows:

$$C_p = \left(\sum_{i=1}^{n} L_i + W_p\right)/\left(1 - \sum_{i=1}^{n} Y_i - Y_p\right)$$

and,

$$C' = \frac{0.9 \sum_{i=1}^{n} L_i + W_p}{0.9 - \sum_{i=1}^{n} Y_i - Y_p}$$

where C_p = cycle length to satisfy the minimum green requirements by P phase with 100% capacity utilization by the other phases.

C'_p = same as C_p except for only 90% capacity utilization by the other phases.

W_p = minimum green for p phase.

Y_p = critical y-ratio for p phase.

Green times using the new cycle length C_p are then again calculated for the remaining green intervals (after having set the green time for the current interval equal to its minimum walk time) and compared to the walk times. Should calculated greens again be less than minimum requirements the process is repeated a second time using W_p and Y_p equal to the sum of the two critical green intervals. This process is repeated until all greens times have been set to minimum walk time or until capacity requirements result in calculated green times greater than the walk times.

C.2.2.4 Final cycle length candidates

Based on the cycle lengths computed above, two final candidates are chosen, one as a minimum requirement and the other as a practical value. The final minimum cycle length (C_M) is given by:

$$C_M = \max(C_w, C_p)$$

The final practical cycle length (C_o) is given by:

$$C_o = \max (C'_w, C'_p)$$

It should be noted that the value of C_M will never exceed that of C_o. Both C_M and C_o are bound by the following limits:

$$\max (C_{min}, C_A) \leq C_o, C_M \leq C_{max}$$

where C_A = absolute minimum cycle length based on minimum green requirements ≥ 40.
C_{min} = minimum practical length provided as an input.
C_{max} = maximum kickout cycle length provided as an input.

Further C_O and C_M will be set to the next highest value of Cmin x KxINCR where INCR is the cycle length increment on card type 2 and K is an integer. Thus C_O and C_M may also vary depending upon the selected cycle length increment.

The cycle lengths used in most traffic signal systems are generally within the range of 40 to 120 seconds. The values of C_O and C_M are used in subsequent subroutines for the selection of system cycle length candidates and for determining whether a given intersection should be coordinated within the system or placed under isolated control.

C.3 System Signal Timing Computations

For each candidate system cycle length, up to a maximum of ten, SSTOP performs the following general functions:

1. It calculates signal timing intervals for both the co-ordinated and the isolated signals in the network.

2. It computes ideal offset settings for the coordinated signals.

3. It searches for a set of optimum offsets closest to the computed ideal offsets.

4. It evaluates the system by calculating the summing delays and stops for all the signals.

The signal timing calculation for the co-ordinated signals is handled by the FLOPAT subroutine. At this point in the program, all the signals in the network are treated as coordinated since the extra computing time involved was found to be insignificant. The signal timings computed by FLOPAT for the isolated signals are simply ignored in the latter stages of the program.

For a given candidate system cycle length C, the green time G for each phase of any signal is calculated by means of the following general equation:

$$G = \left(Y / \sum_{i=1}^{n} Yi\right) C - \sum_{i=1}^{n} Li$$

where Y = critical volume-to-saturation flow (y) ratio for the phase in question.
Y_i = critical v/s ratio for the ith phase.
L_i = total lost time for the ith phase.
n = number of phases.

A check is then made to ensure that the computed green time is greater than or equal to the input minimum green requirement. If one or more minimum green constraints are not met, the green times for these intervals are set to the required minimum. The remaining green time is then proportioned among the other green intervals according to the ratio of the Y ratios. Also, the sum of the green intervals and clearance times for all the phases should be equal to the trial cycle length, C. Otherwise, the difference is added to the interval having the longest green time.

After the signal timing computation for all the intersections in the network have been completed, the timing information along with the approach volumes and the input saturation flow values are stored in a format suitable for the subsequent ideal offset analysis. The data sets are summarized sequentially by green interval with respect to each link. A typical signal sequence would consist of a red interval during which no flow takes place, followed by a green interval during which a traffic flow may occur at a possible maximum rate equal to the input saturation flow value. Along with the length of the green interval, the approach volume, the saturation flow value and the duration of the subsequent clearance intervals are included in the data summary. With the red duration, however, no other data need be specified. Links active in both intervals of a split phase have green periods equal in length to the sum of the two green intervals plus the clearance time separating the two green intervals. The entered clearance time would be that following the second green interval.

C.3.1 Signal Timing Design for Isolated Control

Before computing ideal offset settings for the coordinated signals, those intersections to be placed under isolated control have to be identified and separated from the network. This function is performed by the KIKOUT subroutine.

A number of inequality tests are made among the various cycle lengths as calculated by the SPRITS subroutine to determine if a signal should be isolated from the co-ordinated system.

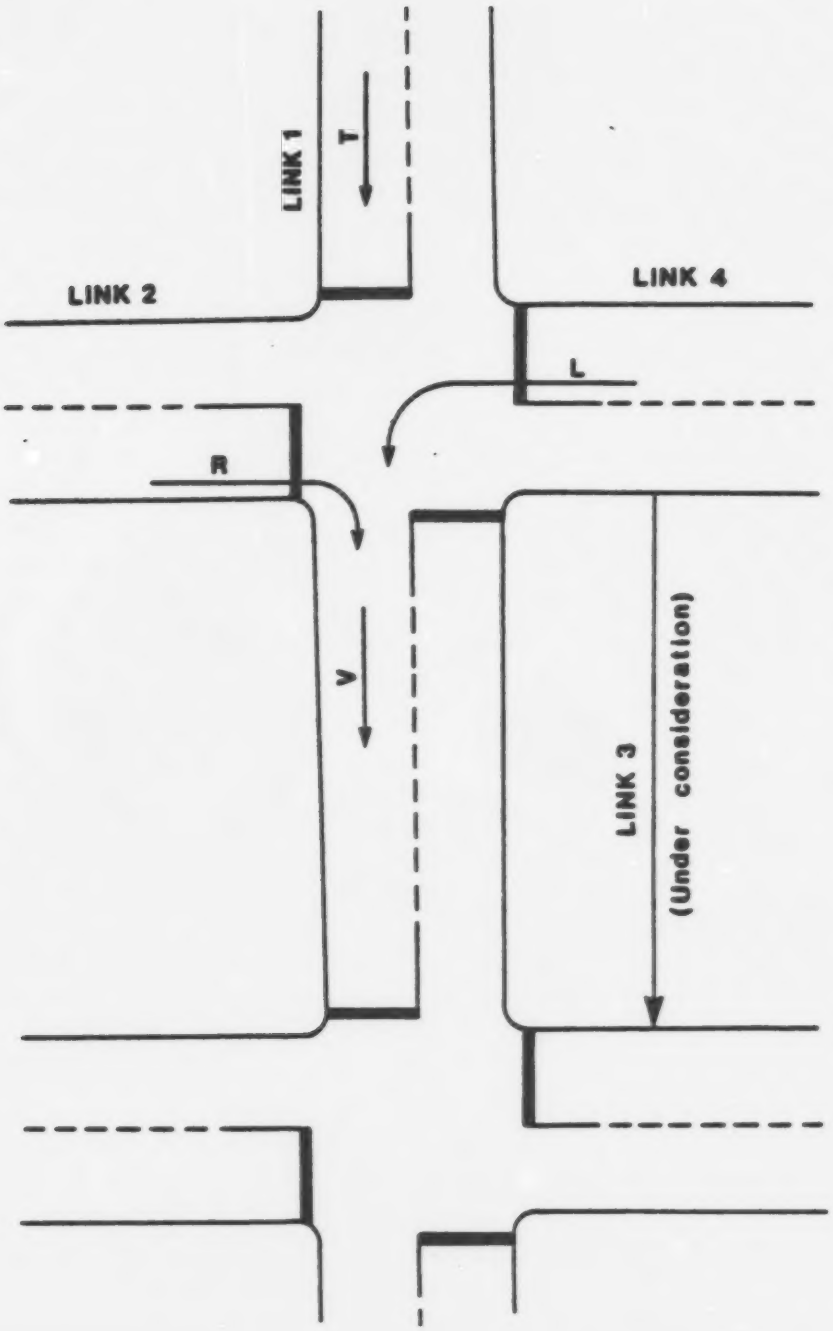
1. A signal is to remain in the system if $C \geq C_O \geq C_M$
   where C = candidate or trial cycle length of the system.
   C_O = optimum cycle length for the signal in question, as computed in the SPRITS subroutine.
   C_M = minimum cycle length for the signal.

   In this case, no further computation will be made in this subroutine.

2. If $C_O \geq C \geq C_M$ the signal will also remain coordinated.

3. If however, $C_O \geq C_M > C$ the signal will be isolated from the network, in which case the value of C_O will be used for the optimum individual control and the subsequent analysis in the KIKOUT subroutine will be applicable.

4. A check is then made to determine if any signals have been isolated from the remainder of the network to be coordinated because of step 3. If so, these signals must also be excluded from the optimization.



LEGEND

T	Through departures
L	Left turn departures
R	Right turn departures
V	Entry flow

Figure C.1 - Entry Flow on a Typical Link

C.3.2 Computation of Delay/Difference-of-Offsets Relationships

After the isolated signals have been processed, SSTOP uses a subroutine called IDEALO to prepare the remaining signals in the system for offset optimization. The IDEALO subroutine performs the following tasks:

1. Generation of link entry flow patterns using the signal and volume data at the upstream node.

2. Formation of link exit flow patterns at the downstream node by means of a platoon dispersion model.

3. Computation of delay/difference-of-offsets and stop/difference-of-offsets arrays.

4. Identification of the ideal offset for each link.

5. Calculation of link importance factors.

Before these tasks are carried out, the subroutine checks to ensure that each link under consideration does not fall into one of the following categories:

1. An external link at the boundary of the network.

2. An left-turn link for a split-phase arrangement.

3. A link associated with an upstream or downstream signal which has been separated from the network.

No coordinated design is required for these types of links, and they will be ignored for the remainder of the subroutine.

C.3.3 Generation of Link Entry Patterns

The traffic flow pattern at the entry point of a link evolves from the departures released by the upstream signal in the direction of the link in question. For a typical link as depicted in Figure C.1, the entry flow consists of through departures T, from Link 1, left-turn departures L, from Link 2 and right-turn departures R, from Link 4. The values of T, L and R are derived from their respective approach volume turn percentages.

To generate the departure patterns, the arrivals at the upstream approaches are assumed to be uniformly distributed throughout the entire cycle length and are then released through the signal in 2-second intervals, starting at the beginning of the cycle according to the following rules:

1. No departures take place during the red interval.

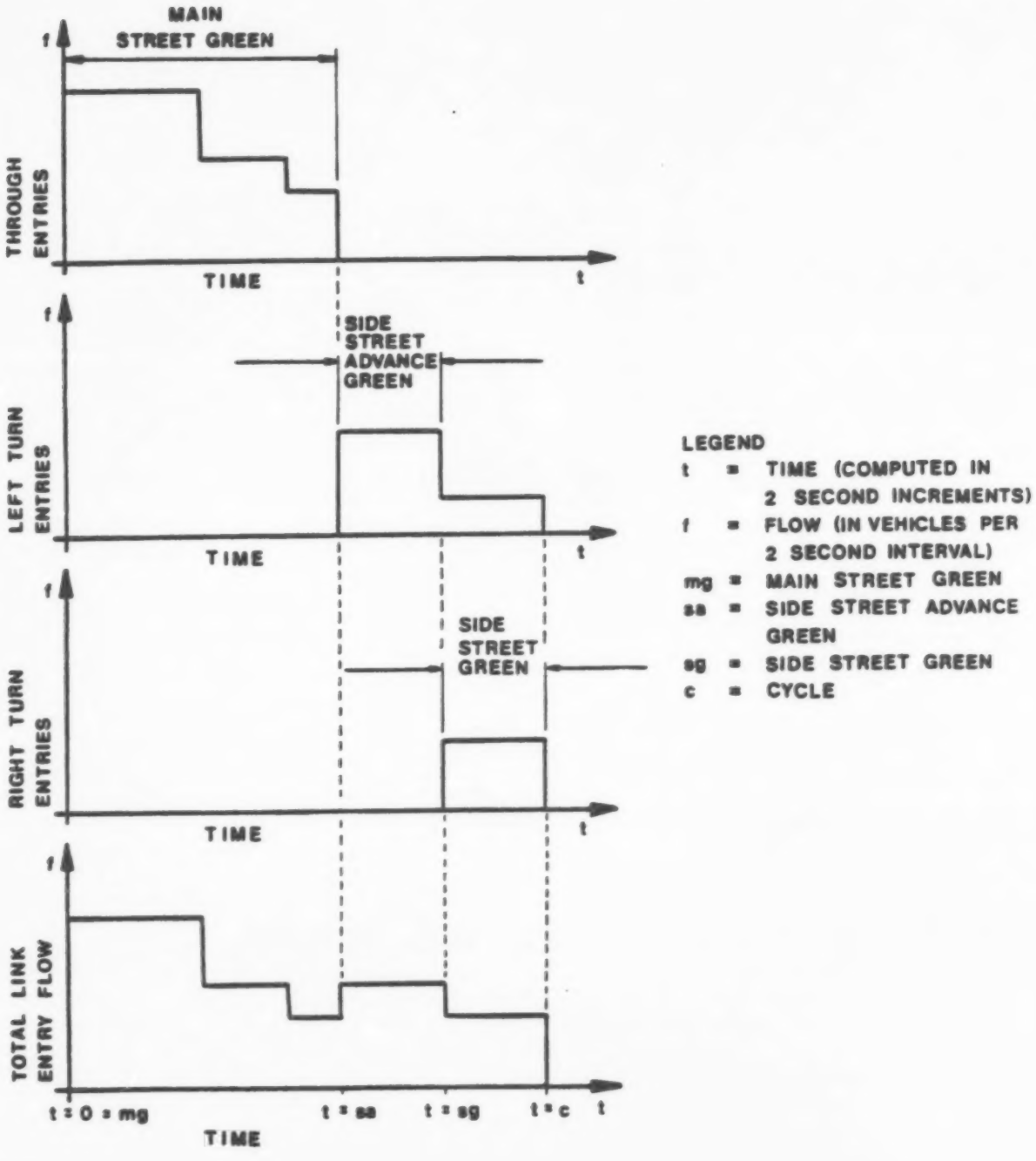


Figure C.2 - Total Link Entry Flow Pattern

2. For any 2-second interval during the green aspect, the departure rate is equal to the saturation flow rate if the demand by the residual queue and new arrivals exceeds the maximum possible number of releases. Otherwise, the release rate will be equal to the rate of demand.

The departure patterns for the individual flow components of T, L and R are represented by histograms of flow values in 2-second steps. These histograms are simply combined to form an overall histogram to depict the total link entry flow pattern, as illustrated in Figure C.2. This provides an upstream flow profile for the link under consideration from which the arrival pattern at the downstream signal can be predicted and analyzed.

C.3.4 Downstream Arrival Computation

In predicting the arrival profile at the link exit signal, allowance is made for the effect of dispersion of the traffic platoon as it travels downstream along the link. Robertson's platoon dispersion model is used for this purpose. The model applies the following recurrence smoothing equation to the link entry flow histogram:

$$q'(i + T) = Fq_i + (1-F)q'_{(i + T - 1)}$$

where q_i = upstream flow during interval i.
$q'(i+T)$ = predicted downstream flow in the $(i+T)$th interval corresponding to the ith interval upstream.
T = a fraction (β) of the input average journey time (t) in number of computation steps.
F = an empirical smoothing factor.

The value of F is given by:

$$F = 1/(1+\alpha\beta t) \text{ or } 1/(1+\alpha T)$$

where $T = \beta T$, an integer value.
α, β = empirical parameters.

Robertson suggests an α value of 0.5 and a β value of 0.8, but it was found in a sensitivity analysis that, although these values provide reasonable results, more accurate platoon predictions can be obtained if α and β are first calibrated for local conditions. As a default value, SSTOP assumes that the product of α and β is 0.25. This value may be altered through the use of the optional card 5.

The platoon prediction procedure as contained in this program has the following special features:

1. In calibrating the model, the product of α and β, denoted by K, is calibrated rather than analyzing their individual values.

2. A trial value of $\beta = 0.8$ is first used to calculate βt. After βt is rounded off to the nearest integer T, a new β is calculated as:

$$\beta = \frac{T}{t}$$, with the condition that 0.7 0.9

where T = integer approximation of 0.8t
t = average journey time.

Then, α is given by:

$$\alpha = \frac{K}{B}$$

The value of F can then be computed as a function of and T.

3. To improve the accuracy, the following special equation is introduced to predict the flow value during the first downstream interval:

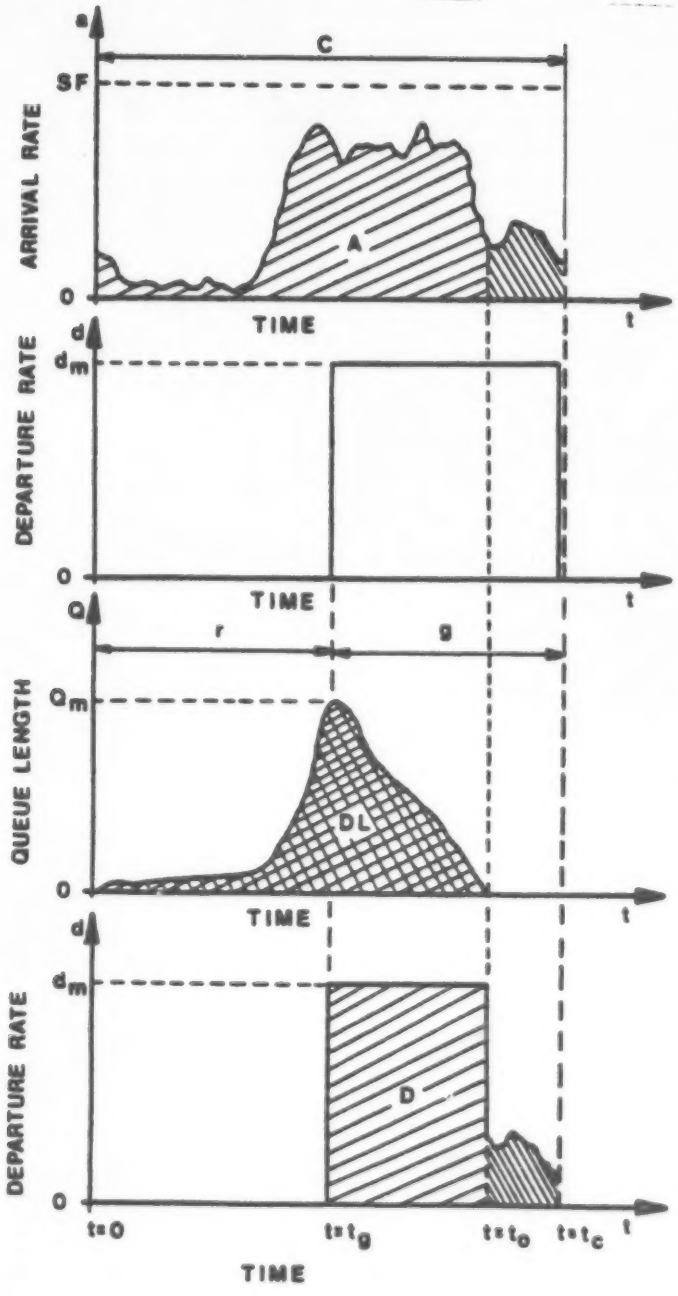
$$q'_{(1+T)} = F \sum_{j=0}^{n-1} q_{(1-j)} (1-F)^{j} \qquad 1-(1-F)^{n}$$

where q'(1+T) = flow during first downstream interval.
F = smoothing factor.
n = total number of intervals.
j = index denoting the interval preceding the first upstream interval. For example, a j value of 1 denotes the interval at the end of the previous cycle, and so on.
q(1-j) = flow during the upstream interval corresponding to the interval (1-j).

4. After the first downstream interval is processed, Robertson's recurrence equation is used to predict all subsequent intervals.

5. When the platoon prediction is completed, the resultant downstream volume is then compared with the input approach volume. If a discrepancy exists, the entire downstream flow histogram would provide a total value identical to the given input volume. In this manner, traffic flow fluctuations along the link due to sources and sinks are taken into account.

The downstream arrival profile is projected from the flow input at the link entry in passenger car units. In preparation for the subsequent delay and stop computation, the profile is converted to through car units to reflect the effect of turning movements.



LEGEND

- t = TIME
- a = ARRIVAL RATE
- A = CUMULATIVE ARRIVALS
- SF = SATURATION FLOW
- d = DEPARTURE RATE
- D = CUMULATIVE DEPARTURES
- d_m = MAXIMUM DEPARTURE RATE
- Q = QUEUE LENGTH
- Q_m = MAXIMUM QUEUE LENGTH
- DL = DELAY
- C = CYCLE
- r = RED INTERVAL
- g = GREEN INTERVAL

Figure C.3 - Traffic Transition Process at a Typical Link's Exit Signal

C.3.5 Performance/Difference-of-Offsets Relationships

The delay and stop computation in the IDEALO subroutine is based on the logic in the GLC-Combination Program. It is assumed that the delay to traffic along a link connecting two coordinated signals with given splits depends solely on the difference of offsets between the two signals. For every offset difference between the upstream and downstream signals, there exists a pair of delay and stop values which can be computed from the arrival and departure patterns at the link exit signal. While the arrival profile is projected from the upstream link entry flow, the departure pattern is based on the downstream signal timing, offset setting, saturation flow and arrival rate. After the arrival histogram has been obtained, a maximum possible departure histogram is set up for each link. During the red aspect, no departure can take place, while during the green interval, the departure may be as high as the given saturation flow. The delay and stop computation is based on the following concepts as depicted in Figure C.3:

1. During the effective red interval, no departure takes place, with the result that arrivals are stopped and delayed. Mathematically:

   (i) Departure rate during the red interval, $d_r = 0$
   (ii) Cumulative departures during the red interval, $D_r = 0$; and
   (iii) The queue length (Q_r) is given by the cumulative arrivals (A_r) as:

$$Q_r = A_r = \sum_{t=0}^{tg} a_t$$

   where a_t = arrival rate during the red interval.
   The delay (DL_r) and number of stops (S_r) are then given by:

$$DL_r = \sum_{t=0}^{tg} (Q_t \Delta t)$$

$$S_r = A_r$$

   where Δt = length of computational interval. A 2-second step is used in SSTOP.
   t_g = time at start of green.

2. At the start of effective green t_g, the arrivals accumulated during red are dissipated at a maximum departure rate d_m equal to the saturation flow. However, new arrivals are still delayed and stopped but the queue is diminishing assuming that the arrival rate cannot exceed the departure rate. The saturation flow condition is assumed to persist until the queue completely disappears at time $t=t_o$.

   That is $d_t = d_m$

$$D_t = \sum_{t=tg}^{t_o} d_m$$

Then, $Q_t = A_t - D_t$

$$= \sum_{t=0}^{t_o} a_t - \sum_{t=tg}^{t_o} d_m$$

Similarly, the delay DL_g and number of stops S_g during the green interval are given by:

$$DL_g = \sum_{t=tg}^{t_o} (Q\Delta t)$$

$$S_g = \sum_{t=tg}^{t_o} a_t$$

3. There is no queue at the signal after $t=t_o$. After this point, new arrivals move freely across the intersection without delay and stops, and the departure rate is equal to the arrival rate. That is:

$$d_t = a_t$$

$$D_t = \sum_{t=t_o}^{t_c} a_t$$

$$Q_t = 0$$

where t_c = time at the end of the signal cycle.

Finally, the total delay and number of stops over the entire one hour control period are given by:

$DL = (DL_r + DL_g)/C$ in vehicle-hours
$S = (S_r + S_g)/C$ in vehicle stops
where C = trial system cycle length.

The above delay value accounts only for the effect of coordination, and does not allow for capacity constraints, thus rendering the value inappropriate for cycle length comparison. To complete the delay computation, a random delay component (R) is included, which is given by:

$$R = ((Bn/Bd)^2 + (x^2/Bd))^{\frac{1}{2}} - Bn/Bd$$

where: $Bn = 2(1-x)+xz$

$Bd = 4z - z^2$

$z = (zx/v)$

x = degree of saturation

v = volume on link (vph)

It should be noted that the value of R is not a function of the offset setting but it is convenient to include it at this stage of the SSTOP package.

To indicate the overall traffic performance of the link under consideration, a performance index P_c is calculated as:

$$P_c = DL + R + KS/3600$$

where K = stop penalty factor set on card type 2, columns 35-40.

The above performance index is calculated for a given offset difference between the upstream and downstream signals. If the downstream offset is altered, the relationship between the arrival and departure profiles is changed, thus giving a different performance index value. For N computational steps in a cycle, there are N possible offset differences and therefore N performance indices. The best offset difference for the pair of signals in question is given by the minimum value of the performance index array. The relationships between offset difference and the various traffic measurements described above are illustrated by the example depicted in Figure C.4 and C.5.

C.3.6 Measure of Link Importance

As a means of indicating the relative importance of a link in the network, the area between the performance index curve and the mean performance index value is used as a measure. This area A for each link is calculated in the IDEALO subroutine as:

$$A = \sum_{i=1}^{n} P_{ci} - \bar{P}_c$$

where P_{ci} = performance index for the ith interval.

P_c = mean performance index.

n = number of intervals in the cycle.
i = index denoting an interval from 1 ... n.

Logically, the importance of a link is analogous to the sensitivity of its performance towards the choice of offset difference. For highly important link, the performance curve tends to have sharp curvatures and the associated A value tends to be large, as illustrated in Figure C.6.

In this case, an offset close to the ideal value should be implemented. For an unimportant link, the curve is relatively flat and the value of A is small, in which case the use of an "ideal" offset is not essential.

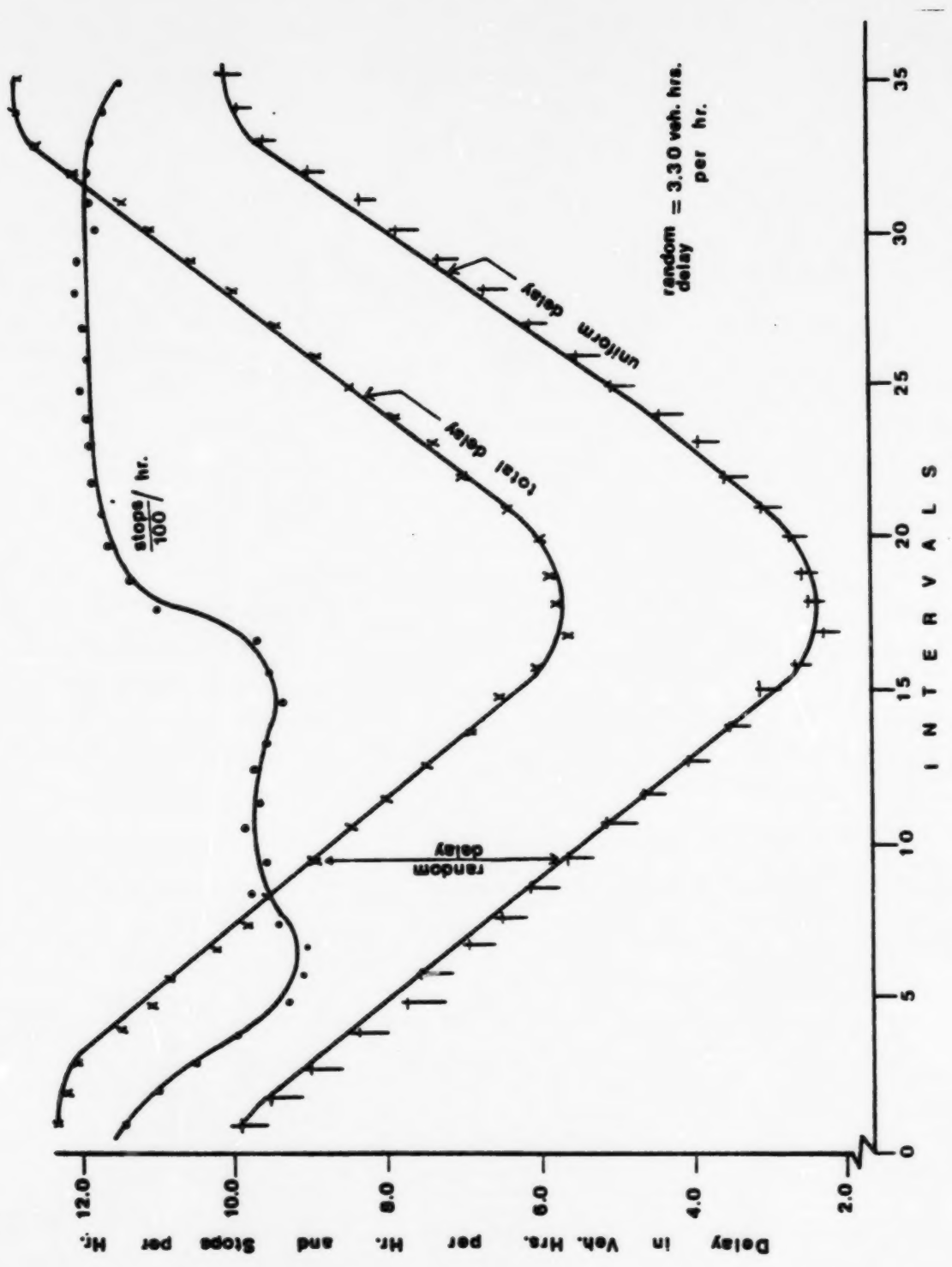


Figure C.4 - Delay-Offset and Stop-Offset Curves

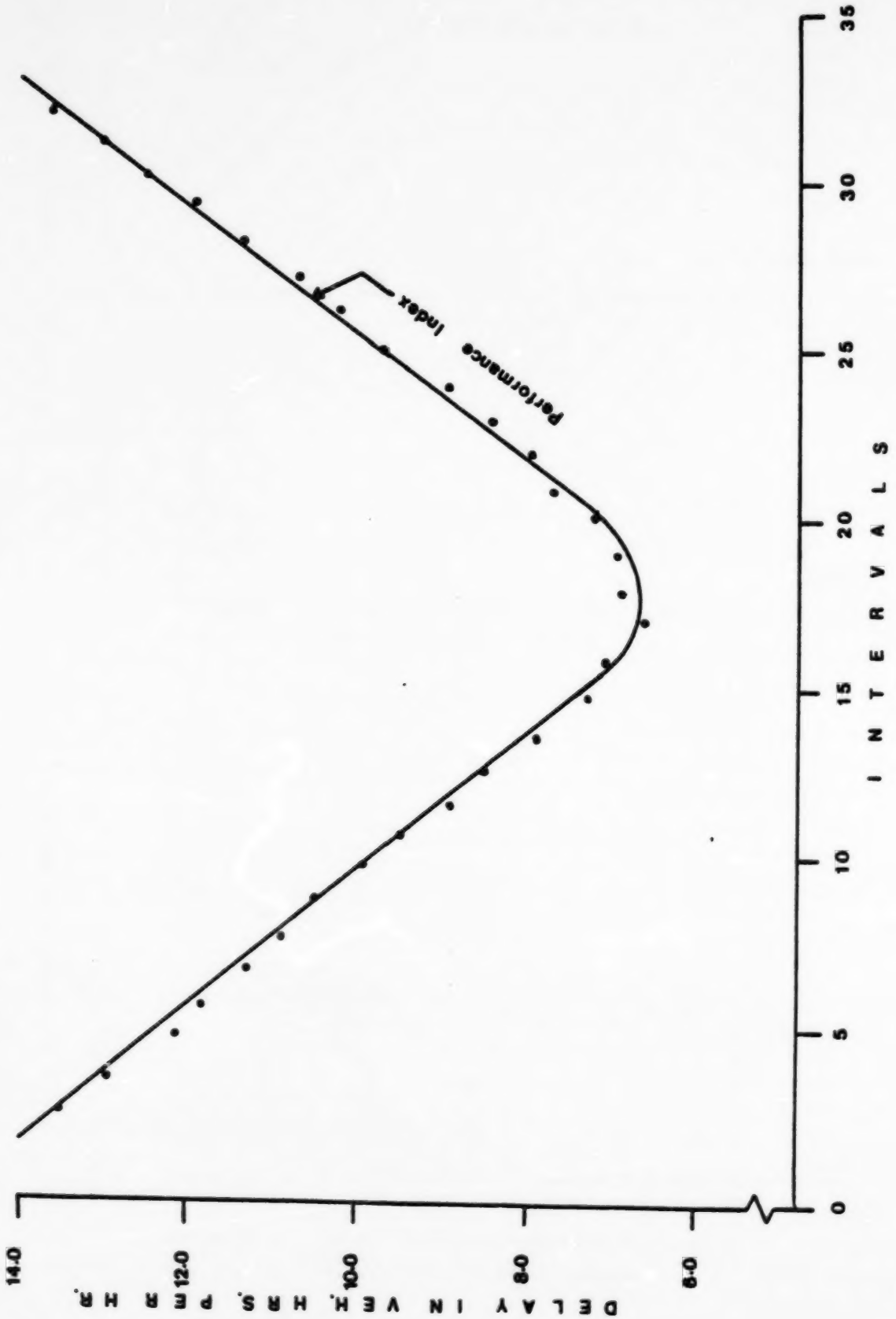
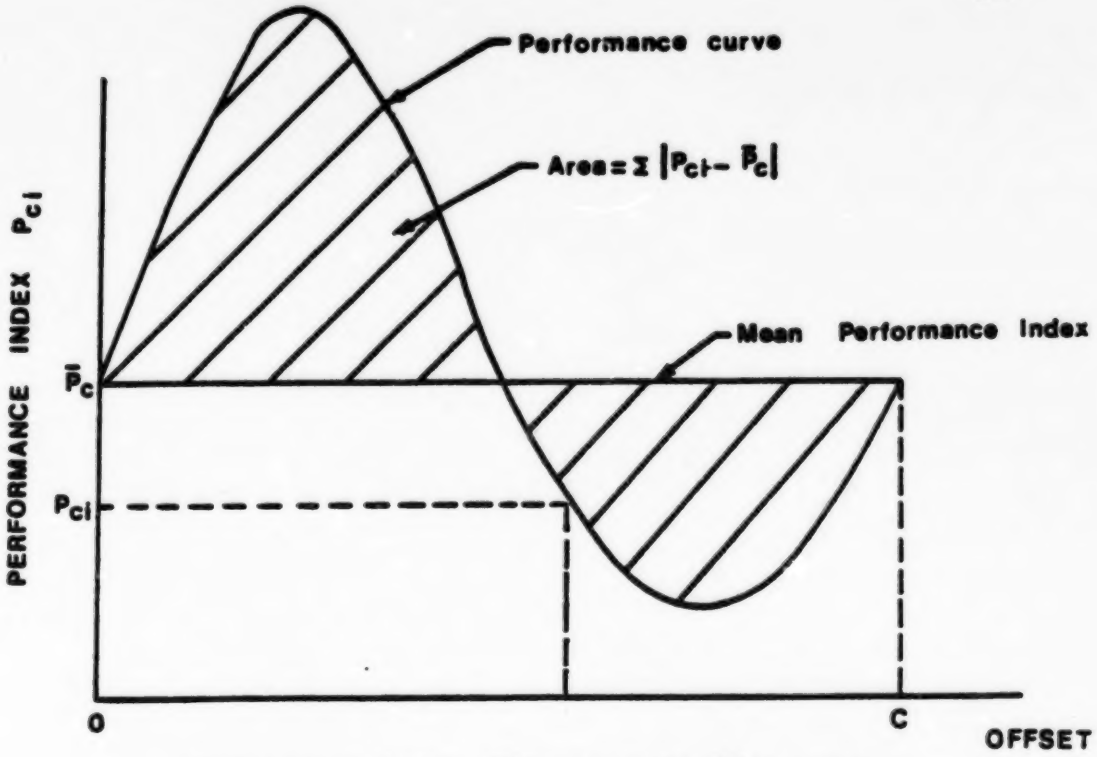
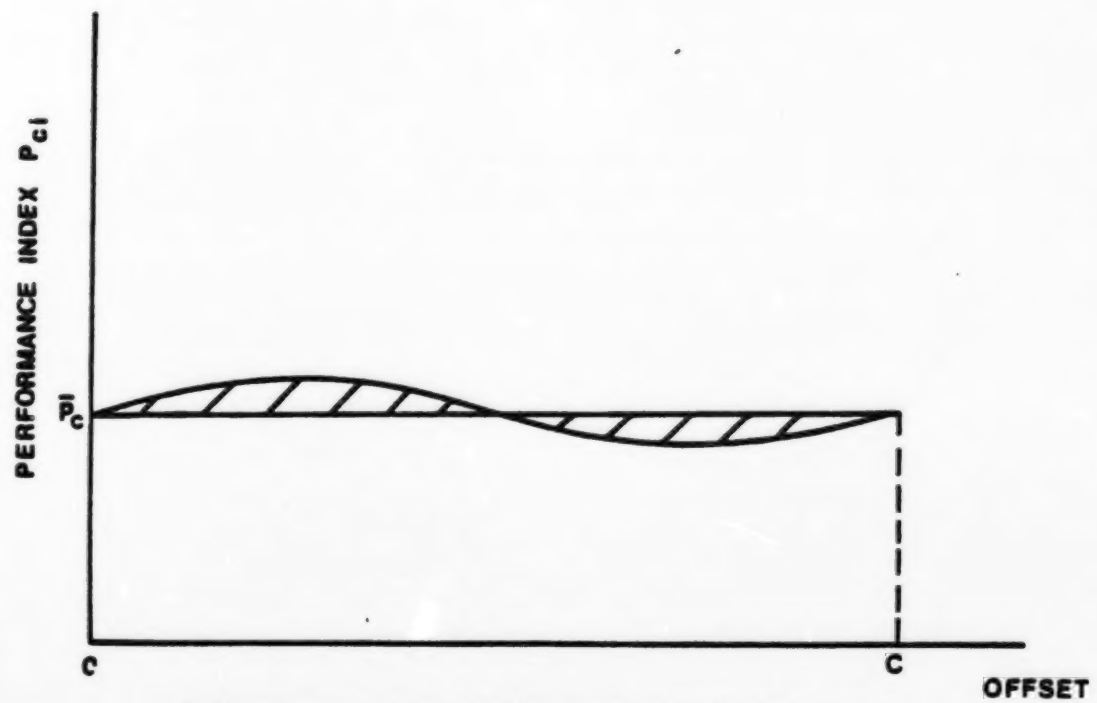


Figure C.5 - Performance Index - Offset Curve



Performance Index / Difference-of-offset curve for a link sensitive to offset choice



Performance Index / Difference-of-offset curve for a link not sensitive to offset choice

Figure C.6 - Performance Index Difference-of-Offset Curve for a Typical Link

C.3.7 Link Ranking Process

The offset optimization algorithm in the program requires as input as a set of importance factors for all the coordinated links in the system. The IMPORT subroutine is used to calculate these factors using the link importance measure A, produced by IDEALO. First of all, the maximum value of A among all the links is identified. Then the link importance factor I, is computed as follows:

$$I = A/A_m \times 100 \times IM/10$$

where A = area between the performance curve and the mean performance index for a given link.
A_m = maximum value of A corresponding to an I value of 100.
IM = importance factor multiplier from Card Type 4, columns 56-60.

The default value for the importance factor multiplier is 10, which when divided by 10 in the equation, results in a scaling factor of 1.0. This provides a set of factors in the range of 1 to 100 which serve as indications of relative importance with respect to the most critical link in the system.

C.3.8 Offset Optimization Algorithm

Prior to offset optimization a subroutine called SUBNET is used to identify any subnetworks which occur as a result of KIKOUT. For example, for a network consisting of two intersecting arterials it is possible that the interconnecting signal may be kicked out. In this situation, the network will consist of four subnetworks, each of which may be optimized separately.

Since the offset optimization algorithm contained in subroutine SIGOS is capable of optimizing only one network (or subnetwork) at a time, a further subroutine NETWRK is required to compress the network structured data into the subnetwork structured format required by the SIGOS subroutine.

Subroutines NETWRK and SIGOS are therefore accessed as many times as there are identified subnetworks.

The optimization algorithm in SIGOS is adapted from the SIGRID program.

1. Ideal offset setting.

2. Link importance factor.

The performance-index/difference-of-offset relationship of a link with given upstream and downstream signal splits can be generally described by a cubic function with one minimum and one maximum. The part of the curve which is of major interest is the portion around the minimum.

For the purpose of offset optimization, it is mathematically convenient to assume the performance/offset curve to be in the form of a quadratic equation. The half-portion of the curve with the minimum performance index offset as the midpoint can be approximated by a parabolic function, as illustrated in Figure C.7. This approximation is valid according to a curve fitting analysis which shows that there is usually a good fit between a parabolic function and the minimum region of the performance/offset curve. Although the parabola will significantly overestimate the performance index for the remaining portion of the curve, this will tend to penalize the choice of poor offsets in the optimization process and is considered a good feature.

The parabolic approximation is given by the following general equation:

$$Y = Ax^2 + B$$

where Y = performance variable
X = offset variable
A,B = constant coefficients

In terms of upstream and downstream offset settings, the performance function for a given link can be expressed as follows:

$$f(\theta_{ij}) = Iy\ (\phi_{ij} + My + \theta_i - \theta_j)^2 + \delta_y$$

where $f(\theta_{ij})$ = performance index for link ij
i = upstream node index
j = downstream node index
θ_i = offset at node i as a fraction of the cycle length.
θ_j = offset at node j as a fraction of the cycle length.
M_{ij} = an integer to maintain periodicity such that
$$-\tfrac{1}{2} \leq \phi_{ij} + M_y + \theta_i - \theta_j \leq \tfrac{1}{2}$$
I_{ij} = link importance factor equivalent to the curvature of the parabola
ϕ_{ij} = ideal offset difference between signals i and j, as a fraction of the cycle length
δ_{ij} = a constant equivalent to the minimum performance index.

The overall system performance function, $F(\theta_{ij})$ is given by:

$$F(\theta_{ij}) = \sum_{i=1}^{n} \sum_{j=1}^{n} (I_{ij}(\phi_{ij} + M_{ij} + \theta_i - \theta_j)^2 + \delta_{ij})$$

where n = number of intersections in the system.

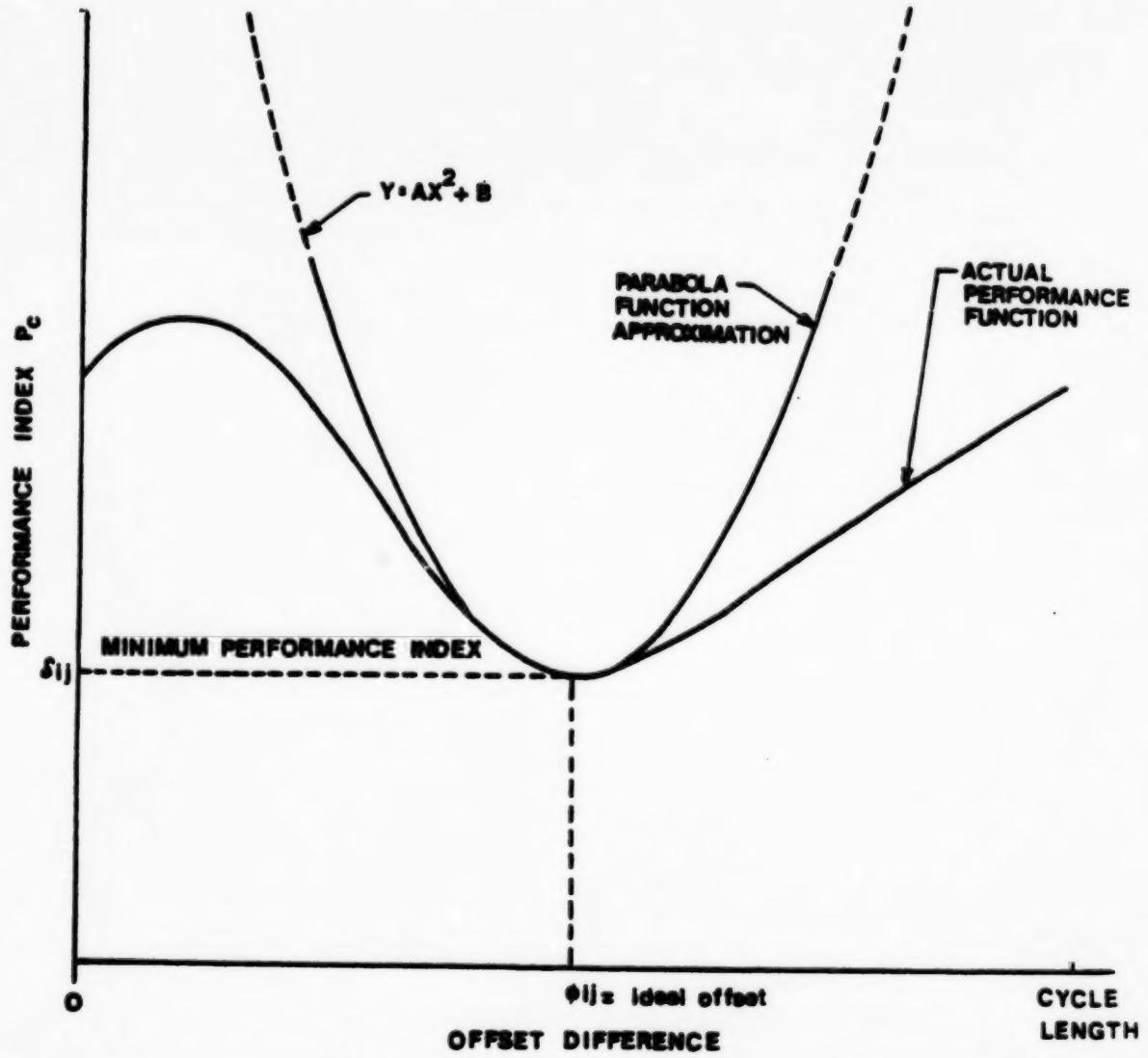


Figure C.7 - Quadratic Approximation of a Link Performance Function

It should be noted that the value of I_{ij} is derived from the total performance curve for the link ij and therefore allows for the effect of the approach volume on the importance of link ij.

For a minimum value of the system performance function, the partial derivatives of the system function with respect to θ_k is:

$$\delta F(\theta_{ij})/\delta\theta_k = 0$$

where K = variable node index from 1 to N for partial differentiation.

This produces N simultaneous linear equations which can be solved for an array of optimum offsets.

In the optimization algorithm of SIGOS, the solution of the simultaneous equations is achieved by manipulating the following matrix equation:

$$\sum_{k=j}^{n=1} d_j B_{jk} = C_k$$

where d_j = offset value of intersection j

$$B_{jk} = -(I_{kj} + I_{jk}) \quad \text{for } k \neq j$$

$$= \sum_{k=j}^{n=1} (I_{kj} + I_{jk}) \quad \text{for } k=j$$

$$C_k = \sum_{k=j}^{n=1} (I_{jk} \times T_{jk} - I_{kj} \times T_{kj})$$

$$T_{jk} = \phi_{jk} + M_{jk}$$

This matrix equation can be transformed into the following form:

$$d_i = \sum_{i=j}^{n-1} E_{ij} C_j$$

where E = inverted matrix of B
d = possible optimum offset

Using this equation, the possible optimum offsets are calculated. However, solving the above equation for all the solutions could be extremely time-consuming since there is a large number of possible outcomes, given by:

$$m = 3^p \cdot 5^{q/2}$$

where m = number of possible outcomes
p = number of links on the one-way streets in the system
q = number of links on the two-way streets in the system

Therefore, a steepest gradient type Monte Carlo search technique is used in the SIGOS subroutine to find the optimum offset values. The optimization algorithm involves the following procedure:

1. A set of random offsets, expressed in fractions of the trial system cycle length, are chosen as the initial trial values for the offset array.

2. The set of offsets corresponding to the minimum value called regional minima of the system performance function are computed by the matrix manipulation described.

3. The system performance function is then transformed to its regional minimum by adding the computed offsets to correct the initial offsets.

4. The neighbouring minima are considered, and the function is transformed to the least neighbouring minimum by offset correction.

5. This is repeated until no better neighbouring minimum can be found.

6. The overall minimum, called a second order minimum, and the corresponding offsets are then stored. This marks the end of the first game.

7. A different set of initial random offsets is then used to start a new game to find another second order minimum. This is repeated until a global minimum value of the system performance function is found or no significant improvement can be achieved. In SIGOS, a minimum of three games must be attempted and a maximum of ten games is allowed.

The optimum offsets are given by the offset values associated with the global minimum system performance function. It should be noted that this function measures merely the discrepancy between the ideal and calculated offsets. It does not measure the real system performance in terms of delay and stops although it provides a relative indication for performance comparisons of different arrays for a given trial system cycle length. The evaluation of actual system performance under different cycle lengths is carried out in the FTABLE subroutine based on delay and stop data from the IDEALO subroutine.

C.3.9 System Performance Evaluation

The optimum offsets computed in SIGOS for the coordinated signals under a given cycle length are first transformed into link offset differences. The corresponding link performance indices are then read from the link-performance/offset-difference arrays which were calculated and stored by IDEALO for the trial cycle length in question. These indices are summed to form a total performance measure for the coordinated portion of the signal system.

To evaluate the performance of isolated signals, external links and priority left turn links, the delay and stop equations developed by Webster are used [5]. The average delay (d) to vehicles at a given approach is given by:

$$d = 9/10 \times C_o(1-G/C_o)^2/2(1-y) + x^2/2_q(1-x)$$

where C_o = optimum cycle length used.
G = green time for the approach in question.
Y = volume-to-saturation flow ratio for the approach.
q = V/3600, vehicular flow in through car units per second.
V = predicted approach volume in units of through cars per hour.
x = qC_o/SG, degree of saturation, where x is $\leq$ 0.9 for priority left-turn links and x $\leq$ 0.95 for external or kicked out links.
S = saturation flow in through car units per second.

The random delay component for these links is greater than that for internal coordinated links since the arrival patterns on the coordinated links are more predictable (less random) than those on external or kicked out links. The above is only an approximate equation but it is sufficiently accurate for practical purposes. The total vehicular delay (D) along the link during the entire one hour period is computed as:

$$D = qd \text{ in vehicle hours.}$$

The proportion of vehicles (E) which are stopped at least once by the signal is given by:

$$E = n/C_o(1-Y)$$

where

$$n = \max\ (C_o-G, (C_o-G)/2+ d)$$

The total number of stops (T) during the one hour control period is therefore given by:

$$T = 3600\ qE$$

In order to discourage excessive stops, the signal system is penalized for vehicular stops by the use of a penalty factor (K) which converts the number of stops into equivalent delay in seconds. For hourly delay units, the factor becomes K/3600. The delay equivalent of stops is then added to the actual delay value to form a performance index (P) given by:

$$P = D + \frac{KT}{3600} \text{ in vehicle-hours}$$

Hence, $P = q(d + KE)$ in vehicle-hours

A K value of 4, as suggested by Huddart {10}, is recommended for SSTOP.

Traffic performance of external links at boundary signals of the network are evaluated in a similar fashion as above. However, if the external link is associated with a signal under system coordination, the value of the system cycle (C) is used through the evaluation process instead of C_o.

These are similarly summed to give a total value. The overall system performance P_o is therefore given by:

$$P_o = \sum_{i=1}^{m} P_{ci}(\theta_{ci}) + \sum_{j=1}^{n} P_j$$

where $P_{ci}(\theta_{ci})$ = performance index of coordinated link i under cycle length C for computed offset difference θ_{ci}
m = number of coordinated links
P_j = performance index of isolated link j
n = number of isolated links.

After printing out the optimal signal settings and performance data for that cycle in subroutine FTABLE, SSTOP then reverts back to the FLOPAT subroutine and performs all the subsequent functions for another trial system cycle length, thus giving another P_o value. After the entire range of practical cycle lengths has been similarly processed for the network, a subroutine called FINAL prints out a set of system performance measures for each trial cycle and indicates which is the optimum.

APPENDIX D - CODING FOR SPECIAL FEATURES AND SAMPLE NETWORK OUTPUT (WATERLOO)

(Prepared by DeLCan)

This Appendix has been prepared by J. Lam and P. deGroot of DeLCan to further aid users in the preparation and interpretation of typical network timing analysis.

D.1 CODING FOR SPECIAL FEATURES

To simulate the traffic flow pattern along a link, SSTOP requires the specification of all links which feed into this link. Figure D.1.1 shows a small network in Waterloo. For link 262, the source node is 28, with 281 as the right turn source link, 282 as the through source link, and 283 as the left turn source link. In cases where the signals appear in a normal grid configuration, it is not necessary to code the source links (for links numbered 1-4), since SSTOP will provide the relevant information, assuming the recommended link directional code has been adopted.

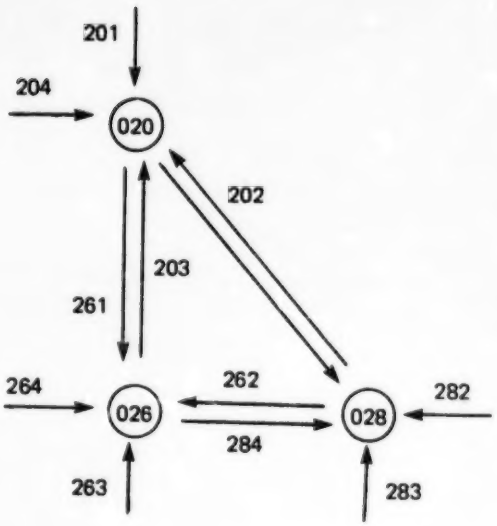


Fig. D.1.1

However, if

1. the network does not conform to the standard grid pattern (e.g., E/B link entrance becomes S/B link exit (281));

2. the link number is greater than 4 and is not a parallel link;

3. an additional fourth source link is feeding into the intersection; then the source links must be explicitly coded.

D.1.1 Traffic Characteristics

The accurate description of saturation flow volume and turning movements is critical for determining the optimum cycle length and split at an intersection. The following points should be considered when coding these values:

1. SSTOP determines from this information, the critical V/S ratios for each phase. If one lane is heavily utilized while other lanes handle little traffic, combining these lanes together to produce total approach values will mask the requirements of the critical lane. An example would be an approach with lightly used exclusive left and right turn lanes and a heavy through movement (Section D.1.2.1, D.1.2.2). Another case would involve two through link exit lanes feeding into one downstream link lane due to parked vehicles. This would require reducing the calculated saturation flow to reflect the actual departure rate.

2. Link volume is required on a per hour basis. However, if a signal timing plan is desired to handle short term flow peaks (e.g., 15 min.), the following adjustment should be made:

$$\frac{\text{peak volume}}{\text{peak duration (hrs)}} = \text{representative hourly volume}$$

This adjustment generally results in longer cycle lengths for the time period under consideration.

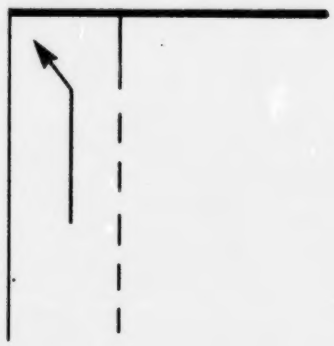
3. Several saturation flow calculation methods are described in Appendix B, with the Toronto method being the recommended approach.

D.1.2 Geometrics

This section addresses difficulties which may arise in SSTOP coding due to the geometric configuration of an intersection. This will affect the determination of representative volumes and saturation flows for each approach under consideration.

D.1.2.1 Exclusive Left Turn Lane

If a special phase for left turn is employed at this approach, the saturation flow and volume for this lane is assigned to the corresponding left turn link. The saturation flow for this lane is 1500 tcu/hr-grn, unless special geometric (e.g., a turn of 90 degrees) entail a slightly lower value (e.g., 1350 tcu/hr-grn).



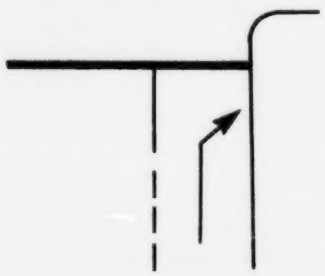
If no special phase is present at this approach and the left turn movement is light, the saturation flow and volume for this lane should not be included in the approach characteristics, since it will incorrectly reduce the volume/saturation ratio for the critical through lanes.

If the left movement is relatively heavy, consideration should be given to modelling the lane as a separate parallel link with a saturation flow of 1500 tcu/hr-grn.

In order to provide the correct tcu conversion factor, links which include an exclusive left turn lane should include the 'LEFT' geometric feature designation in card type 4.

D.1.2.2 Exclusive Right Turn Lane

If the right turn volume is relatively light on this approach, the volume and saturation flow for the exclusive right turn lane should not be included in the approach characteristics.

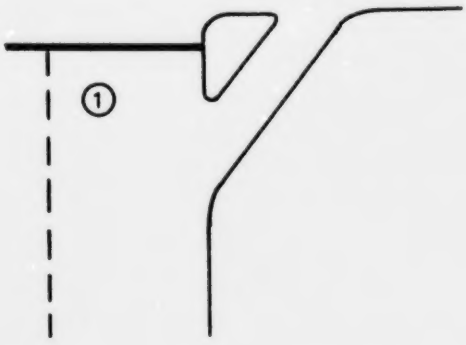


If the right turn volume is relatively heavy, consideration should be given to modelling the lane as a separate parallel link with a saturation flow of 1500 tcu/hr-grn.

In order to provide the correct tcu conversion factor, links which include an exclusive right turn lane should include the 'RIGHT' geometric feature designation in card type 4.

D.1.2.3 Right Turn Island

The effects of a right turn island on SSTOP coding procedures are present only when the saturation flow rate of through vehicles is reduced. This occurs when vehicles, planning to turn right, occupy space in the queue controlled by the traffic signal. Because of the right turn island, the right turning vehicles leave the queue just before entering the intersection. Their effect on other vehicles on the approach can be modelled by multiplying the saturation flow of the affected lane by the fraction of the total lane volume which does not turn right.



Example:
Lane 1 Initial Saturation Flow = 1500 tcu/hr-grn.
Lane volume is 300 vph, of which 100 turn right.
Therefore, adjusted lane saturation flow =

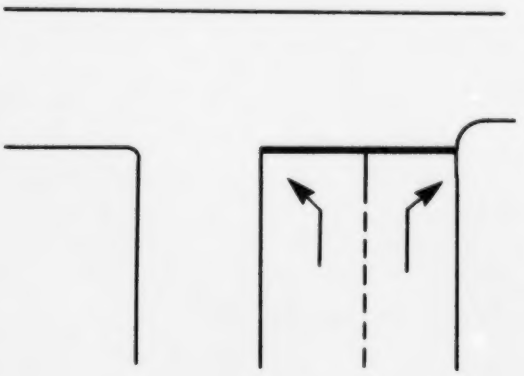
$$\frac{(300 - 100)}{300} \times 1500 = 1000 \text{ tcu/hr-grn}$$

However, judgement must be used in determining when to apply this adjustment factor, ensuring that the flow of the other movements across the stop bar is reduced. For example, if the start of the right turn island is far back of the intersection, the through vehicles will have time to regroup before reaching the stop bar.

In any case, the right turn volume is not included in the SSTOP input, since its delay is not dependent on the link exit signal timings.

D.1.2.4 'T' Intersections

If the turning movements from the stem of a 'T' intersection share the same lane, or if they employ separate exclusive turn lanes, but produce approximately the same volume/saturation (V/S) ratio, then this approach can be modelled by one link.

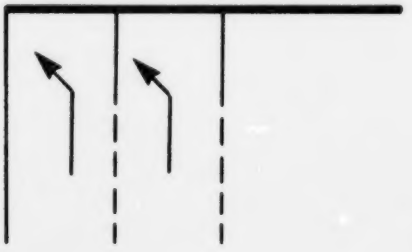


If the V/S ratios for the exclusive lanes are different, consideration should be given to modelling each movement by a separate parallel link. SSTOP will correctly assume that the capacity of each lane is independent of the other.

In order to provide the correct tcu conversion factor, links which comprise the stem of a 'T' intersection should include the 'T' geometric feature designation in card type 4.

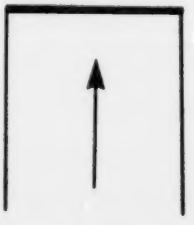
D.1.2.5 Dual Left Turn Lanes

In addition to the procedures discussed in Section D.1.2.1, it has been determined that the saturation flow rate of lane 1 is 80% of lane 2. Thus, the saturation flow for this lane under normal conditions is 1200 tcu/hr-grn.



D.1.2.6 One Way Streets

In the absence of any exclusive turn lanes, the link which designated the one-way approach should include the input 'ONE' in the geometric features column of card type 4.



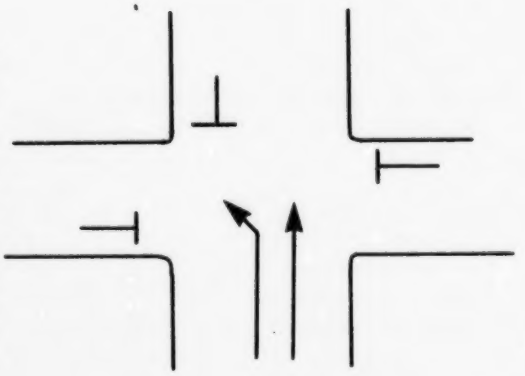
If any exclusive lanes are present on the approach, their designation ('LEFT', 'RIGHT', OR 'BOTH') supersedes the 'ONE' input.

D.1.3 Signal Timing

This section addresses difficulties which may arise in SSTOP coding due to the signal timing configuration at an intersection. This will affect the link designation, saturation flow and timing parameters for each approach under consideration.

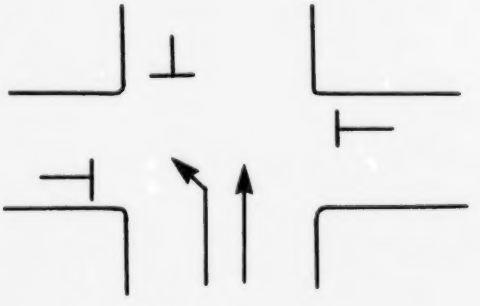
D.1.3.1 Advanced Green

The correct modelling of an advanced green on an approach requires the use of an additional card type 3 with a negative (-) link number (the absolute value of which is the same as the corresponding through link). This negative link card will contain the left turn saturation flow rate, as well as the minimum green permitted for the special phase period. This value must include any clearance interval which precedes the start of normal green.



D.1.3.2 Extended Green

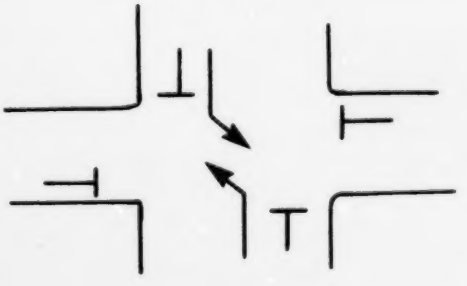
The correct modelling of an extended green requires the use of an additional card type 3 with a positive (+) link number. This positive link card will contain the left turn saturation flow rate as well as the minimum green permitted for the special function interval.



D.1.3.3 Simultaneous Left Turns

These traffic movements must be modelled with a SEPARATE phase. This requires a separate card type 3 and card type 4 for each left turn movement, with corresponding source links, link lengths, phase numbers, saturation flows, etc.

The SSTOP program assumes that these movements are unable to proceed during any other phase in the cycle.



D.1.3.4 Traffic Actuated Control

The SSTOP program has not been developed to handle the special features of traffic actuated control. However, if all of the phases are employed to their maximum duration during the time period under consideration, SSTOP may adequately model the intersection. The resultant signal timings for each phase would become the maximum phase durations for the actuated controllers.

D.1.4 Output Evaluations

Since SSTOP is only a tool in the optimization of network signal timing, it is important that a critical evaluation of the program results be performed. This chapter describes the various methods for evaluating and adjusting the SSTOP program output.

D.1.4.1 Cycle Length

Based on the comparison of performance indices for various cycle lengths, an optimum cycle length for the system is obtained. However, the following qualifications should be considered:

1. if a large cycle length increment (e.g., $\geq$ 10 sec) has been used, a better performance index may be obtained by using smaller cycle increments close to the previous optimum cycle.

2. if one of the boundary cycle lengths is the optimum, the range of cycle lengths considered should be extended beyond the boundary. This will ensure that the true optimum cycle length will be obtained (Figure D.1.2)

3. if Kicked Out signals are present in the network, their traffic parameters should be checked to ensure that they merit such treatment. Representative saturation flows which are too low or volumes which are too high may result in Kicked Out intersections.

4. if the optimum cycle length is higher than expected, a possible cause may be low saturation flows or high volumes at critical intersection in the network. The Cycle Length Calculations table should be reviewed in this instance.

5. if the optimum cycle length is lower than expected, a possible cause may be high saturation flows and low volumes at critical intersections in the network. The V/S ratio for each approach should be checked to ensure accurate modelling of the actual traffic situation.

Volume and saturation flows may be unrealistic due to simple coding errors or due to the assumptions made in determining these values (e.g., hourly volume versus peak 15-minute volume).

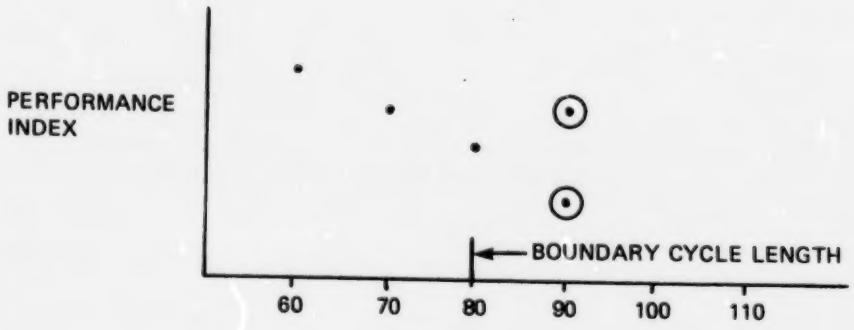


Figure D.1.2

D.1.4.2 Offset

The signal offsets in the SSTOP output are obtained through optimizing the total system performance index. Therefore, resultant offsets between certain signal pairs may incur a significant number of stops. Other signal optimization techniques (such as MAXBAN) may provide better progression along a street, but they tend to result in poorer overall system performance.

However, if an offset appears to be incorrect, the following parameters should be checked:

1. turning movements onto the entrance of the connecting link. If this volume is significant, it will reduce the sensitivity of the signal timings to the arrival of the through vehicles.

2. platoon dispersion effects along the link. If the downstream platoon has sufficiently dispersed (e.g., long link), SSTOP assumes that it is relatively insensitive to signal offset. If field observations reveal platoon cohesiveness at the link exit, consideration should be given to adjusting the platoon dispersion coefficient on a system-wide basis to reflect this. Individual link adjustment can be obtained using the Link Importance Multiplier.

3. competing movements at the intersection. In order to achieve an improved network performance index, an ideal offset may have been given to an opposing movement.

All offsets in the network are related to the time after the start of phase 1 green for the last node listed in the input. This approach permits the joining of adjacent networks by assuring that the last intersection coded is the same for both networks.

If the resulting offset for a particular intersection is unacceptable based on a criterion other than minimizing the network performance, an improved offset can be obtained using the link importance multiplier input. An inputted value greater than 10 will increase the sensitivity of the link to deviations from the calculated ideal offset.

D.1.4.3 Phase Duration

Phase lengths in SSTOP are a function of the V/S ratio on the approach, subject to the minimum green constraints.

If the green time for a phase is relatively short, the following parameters should be checked:

1. the volume and saturation values for the links releasing traffic during this phase. High saturation flows and/or low volumes generally produce short phase lengths.

2. the minimum greens for links employing that phase. If pedestrian movements are present during this phase, minimum green value should reflect this.

If the green time for a phase is relatively long, the following parameters should be checked:

1. low saturation flow rate and/or high volumes will produce long phase lengths. The validity of these inputs should be assessed.

2. lengthy minimum green constraints will result in longer phases and cycle lengths.

Consideration might be given to reducing these values, if possible, at critical intersections.

D.2 SAMPLE NETWORK (WATERLOO)

To assist in coding and performing SSTOP runs, a complete example is contained in this appendix. The network, shown in Figure D.2.1, consists of the downtown Waterloo area and the Bridgeport and Erb Street East arterials. Twenty-five intersections and 93 links are contained in this network, which is being optimized for the pm peak period.

In Section D.2.1, the coding procedure is described and special coding problems are addressed. Section D.2.2 represents a discussion of the program output.

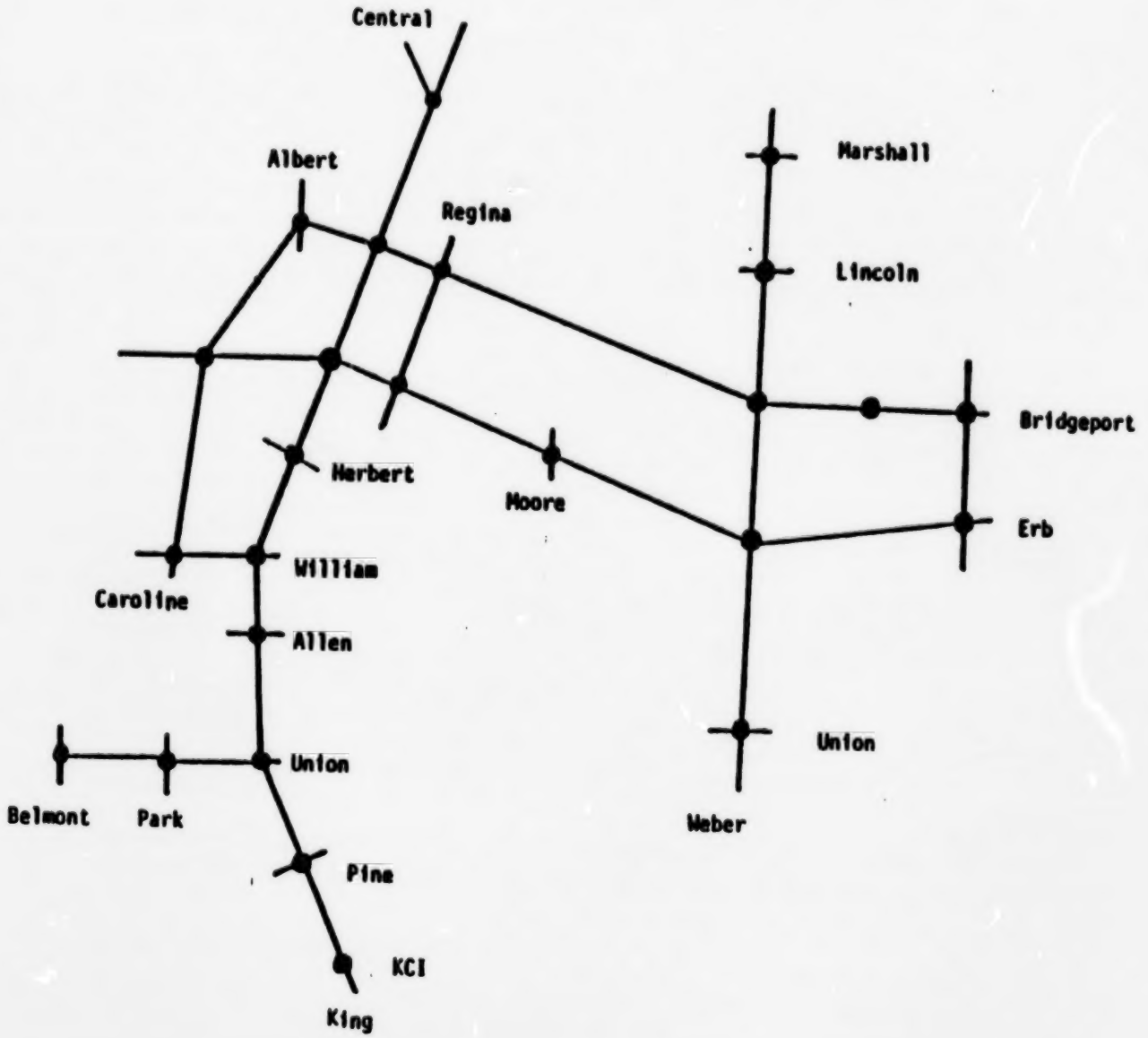


FIGURE D.2.1 Waterloo CBD Network - Signalized Intersection

D.2.1 Network Coding

The link number convention, described in Section 4.1, suggests a clockwise number of links beginning with the southbound link. Because of the unique structure of this network, involving direction changes along major arterials, a slightly modified convention was adopted. King Street links always ended in a 1 or a 3, while Erb and University links end in a 2 or 4. The remaining links were numbered to correspond to these arterials.

Card type 4 requires the identification of upstream source links if these deviate from a regular grid pattern. The only instance where this occurs is at the southbound approach of Caroline and Erb (Link No. 621).

The next step in the coding effort is to gather information concerning intersection geometry and traffic movements. The volumes used in this network were obtained from peak 15-minute detector counts. The saturation flows were calculated using the Toronto Method as described in Appendix B.

A pedestrian signal is included on Bridgeport between Margaret and Bridgeport. The SSTOP program requires the pedestrian movement to be coded as a link with volume and saturation flow values. Arbitrary saturation flow and volumes of 5000 and 50 were chosen to achieve the minimum .01 Volume/Saturation ratio, while ensuring that the pedestrian phase remains at the minimum duration.

The 'geometric feature' input on Card Type 4 adjusts the tcu conversion factor which is applied to turning volumes. The 'one' descriptor is applied to all links on the one-way streets Erb and Bridgeport. In addition, there are numerous links which contain exclusive left and/or right turn lanes and must be designated as such.

The design speed throughout the network is 50 km/h, except for Weber Street which is at 60 km/h. The network was tested for cycle lengths between 60 and 90 seconds, with increments of 10 seconds. A network stop penalty of 4 seconds per stop, the value recommended in Chapter 3, was used.

The SSTOP output includes a summary of the network input data. The Waterloo CBD input is summarized at the end of this Appendix.

D.2.2 Output Interpretation

The first output table produced by SSTOP is entitled "Cycle Length Calculations". For the Waterloo CBD network, two intersections are unable to operate at a 60 second cycle length.

1. Erb and Caroline (#62)

2. Belmont and Urban (#96)

Minimum green constraints combined with heavy opposing movements resulted in minimum cycle lengths of 70 seconds at both these intersections.

A cycle length of 70 seconds produced the lowest performance index for this network. A lower cycle length results in lower uniform delay, but higher random delay and stops per hour. Higher cycle lengths produce fewer stops and random delays, but much higher uniform delay.

In order to assess the performance of each link under the recommended signal timings, the link performance tables should be examined. Of special concern are advanced green links which may not be fully utilized. Such a problem may exist on the eastbound advance link on Union at Park (-984), which has a degree of saturation equal to .820. The opposing movements operate under a high degree of saturation due to the presence of this special function. Consideration might be given to deleting the advanced green during this time period.

An examination of the Degree of Saturation in other links reveals that the southbound links of Caroline at Erb (621) operates at a level of .982. In such cases, it is beneficial to recheck the inputted volume and saturation value to ensure that they accurately reflect actual traffic patterns. The link volume for this approach includes heavy left and right turn movements, whereas the saturation flow value pertains only to the two through lanes. In subsequent runs, the turn movements should be eliminated.

WATERLOO CBD INITIAL OPTIMIZATION - PM PEAK

INPUT DATA-NETWORK PARAMETERS
****

MINIMUM SYSTEM TRIAL CYCLE LENGTH = 60 SECONDS

CYCLE LENGTH INCREMENT = 10 SECONDS

MAXIMUM SYSTEM TRIAL CYCLE LENGTH = 90 SECONDS

MAXIMUM KIKOUT SIGNAL CYCLE LENGTH = 130 SECONDS

NUMBER OF LINKS IN NETWORK = 93

NUMBER OF INTERSECTIONS = 25

NETWORK STOP PENALTY = 4 SEC/STOP

NETWORK CLEARANCE INTERVAL = 0 SECONDS

DEFAULT TO IMPERIAL UNITS

OPTIMIZATION RUN. FULL OUTPUT FOR EACH TRIAL CYCLE

**OPTIONAL CARD 5 HAS NOT BEEN INCLUDED
THE FOLLOWING VALUES ARE ASSUMED

LEFT TURN TCU = 1.750

RIGHT TURN TCU = 1.250

TRUCK AND BUS PCU = 2.000

LEFT TURN VEHICLES CLEARED IN AMBER = 100 PER HOUR

PLATOON DISPERSION FACTOR = 0.25

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
50	501	WEBERMSE	1	3610	12	5
	502	MRSHLWWE	2	1820	15	5
	503	WEBERMNE	1	3596	12	5
	504	MRSHLWEE	2	1820	15	5
54	541	ALBRTBSE	2	1608	14	4
	542	BRIGPAWB	1	5593	10	4
	543	ALBRTBNE	2	1841	14	4
58	581	KING DSB	1	3059	13	4
	582	BRIGPKWB	2	4561	16	5
	-583	KING BNB	1	607	7	2
	583	KING BNB	1	2993	13	4
60	601	REGINBSB	2	1475	15	4
	602	BRIGPRWB	1	4878	14	4
	603	REGINBNB	2	1464	15	4
62	621	CARLNESB	2	3884	13	4
	-623	CARLNENB	2	1380	7	2
	623	CARLNENB	2	2729	13	4
	624	EPB CEB	1	3596	11	6
64	-641	KING ESE	1	965	7	2
	641	KING ESB	1	2993	11	4
	643	KINB ENB	1	3060	11	4
	644	ERB KEB	2	4495	15	5
66	661	REGINESB	2	1459	13	4
	663	REGINENB	2	1475	13	4
	664	ERB REB	1	4763	14	4
68	681	WEBERLSB	1	3660	17	5
	682	LINCNWWB	2	1798	17	5
	683	WEBEPLNB	1	3674	17	5
	684	LINCNWEB	2	1658	17	5

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
70	701	WEBERBSE	1	3717	18	5
	702	BRIGPWWB	2	7542	20	5
	-703	WEBERBNB	1	1680	7	2
	703	WEBERBNE	1	3674	18	5
72	722	BRIGPEWB	1	5601	11	4
	723	PED NS	2	5000	7	9
74	741	MRGRTBSE	2	1869	14	5
	742	BRIGPMWB	1	3868	16	5
	743	MRGRTBNE	2	7869	14	5
76	761	MOOREESE	2	1841	16	5
	763	MOOREENB	2	1841	16	5
	764	ERB MEB	1	5554	16	4
78	-781	WEBEPESB	1	1517	7	2
	781	WEBERESB	1	3689	17	5
	783	WEBERENB	1	3759	17	5
	784	ERB WEB	2	5769	20	5
80	801	MRGRTESE	2	1781	17	5
	803	MRGRTENB	2	3723	17	5
	804	ERB MEB	1	5693	16	5
82	821	KING HSB	1	3060	11	4
	822	HERBTKWB	2	1475	17	5
	823	KING HNB	1	3136	11	4
	824	HEBBTKEB	2	1557	17	5
86	861	CARLNWSB	1	1841	14	4
	862	WILLNCWB	2	1755	17	5
	863	CAPLNWNB	1	1841	14	4
	-864	WILLNCEB	2	1349	7	2
	864	WILLNCEB	2	1300	17	5
88	881	KING WSB	1	3088	13	4
	882	WILLMKWB	2	1409	23	5
	883	KING WNB	1	3060	13	4
	884	WILLMKEB	2	1409	23	5

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-PHASE INFORMATION
****

INT'N NO.	LINK NO.	LINK NAME	PHASE NO.	SATURATION FLOW (TCU/GRN-HR)	MINIMUM GREEN (SEC)	CLEARANCE INTERVAL (SEC)
89	891	KING ASE	1	3075	11	4
	892	ALLENKWB	2	1700	17	5
	893	KING ANB	1	3075	11	4
	894	ALLENKEB	2	1700	17	5
90	901	KING USB	1	3088	12	4
	902	UNIONKWB	2	1677	18	5
	903	KING UNB	1	3088	12	4
	904	UNIONKEE	2	1409	18	4
94	941	WEBERUSE	1	3645	18	5
	942	UNIONWWB	2	1798	19	5
	943	WEBERUNB	1	3631	18	5
	944	UNIONWEB	2	1876	19	5
96	961	BLMNTUSE	2	1755	21	5
	-962	UNIONBWB	1	1647	7	2
	962	UNIONBWB	1	1784	19	5
	963	BLMNTUNE	2	1841	21	5
	964	UNIONBEB	1	1841	19	5
98	981	PARK USB	2	1841	17	5
	982	UNIONPWB	1	1876	19	5
	983	PARK UNB	2	1755	17	5
	-984	UNIONPEB	1	1517	7	2
	984	UNIONPEB	1	1766	19	5
108	1081	KING USB	1	1841	17	5
	1082	PINE KWB	2	1409	13	4
	1083	KING PNB	1	3060	14	4
	1084	PINE KEB	2	1475	13	4
110	1101	KING KSB	1	3060	13	4
	1102	PED WB	2	5000	7	12
	1103	KING KNB	1	3060	13	4
56	561	KING CSB	1	3610	18	5
	563	KING CNB	1	3700	18	5
	564	CNTRLKEB	2	3639	15	4

WATERLOO CBD INITIAL OPTIMIZATION - PM PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.	LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLER
50	501	WEBERMSB	-	-	-	-	10
	502	MRSHLWWB	-	-	-	-	10
	503	WEBERMNB	68	529	60	-	10
	504	MRSHLWEB	-	-	-	-	10
54	541	ALBRTBSB	-	-	-	RIGHT	10
	542	BRIGPAWB	58	181	50	ONE	10
	543	ALBRTBNB	-	-	-	-	10
58	581	KING BSB	56	247	50	-	10
	582	BRIGPKWB	60	94	50	ONE	10
	-583	KING BNB					
	583	KING BNB	64	282	50	-	10
60	601	REGINBSB	-	-	-	-	10
	602	BRIGPRWB	70	815	50	ONE	10
	603	REGINBNB	66	282	50	-	10
62	621	CARLNESB	54	360	50	ONE	10
	-623	CARLNENB					
	623	CARLNENB	86	461	50	-	10
	624	ERB CEB	-	-	-	-	10
64	-641	KING ESB					
	641	KING ESB	58	282	50	-	10
	643	KING ENB	82	179	50	-	10
	644	ERB KEB	62	279	50	ONE	10
66	661	REGINESB	60	282	50	-	10
	663	REGINENB	-	-	-	-	10
	664	ERB REB	64	99	50	ONE	10
68	681	WEBERLSB	50	529	60	LEFT	10
	682	LINCNWWB	-	-	-	LEFT	10
	683	WEBEFLNB	70	135	60	LEFT	10
	684	LINCNWEB	-	-	-	-	10
70	701	WEBERBSB	68	135	60	-	10
	702	BRIGPWWB	72	397	50	ONE	10
	-703	WEBERBNB					
	703	WEBERBNB	78	228	60	LEFT	10

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.	LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLER
72	722	DRIGPWEB	74	291	50	ONE	10
	723	PED NS	-	-	-	-	10
74	741	MEGRTBSB	-	-	-	-	10
	742	BRIGPMWB	-	-	-	ONE	10
	743	MRGRTBNB	80	239	50	LEFT	10
76	761	MOOSEESB	-	-	-	-	10
	763	MOOSEENB	-	-	-	-	10
	764	ERB MEB	66	532	50	ONE	10
78	-781	WEBERESB					
	781	WEBERESB	70	228	60	LEFT	10
	783	WEBERENB	94	587	60	-	10
	784	ERB WEB	76	399	50	ONE	10
80	801	MRGRTESB	74	239	50	LEFT	10
	803	MRGRTENB	-	-	-	-	10
	804	ERB MEB	78	619	50	ONE	10
82	821	KING HSB	64	179	50	-	10
	822	HERBTKWB	-	-	-	-	10
	823	KING HNB	88	224	50	-	10
	824	HERBTKEB	-	-	-	-	10
86	861	CARLNWSB	62	461	50	RIGHT	10
	862	WILLMCWB	88	103	50	LEFT	10
	863	CARLNWNB	-	-	-	-	10
	-864	WILLMCEB					
	864	WILLMCEB	-	-	-	LEFT	10
88	881	KING WSB	82	224	50	LEFT	10
	882	WILLMKWB	-	-	-	-	10
	883	KING WNB	89	240	50	LEFT	10
	884	WILLMKEB	86	103	50	LEFT	10
89	891	KING ASB	88	240	50	-	10
	892	ALLENKWB	-	-	-	-	10
	893	KING ANB	90	360	50	-	10
	894	ALLENKEB	-	-	-	-	10

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-LINK CHARACTERISTICS
****

INT'N NO.	LINK NO.	LINK NAME	UPSTREAM INT'N	LENGTH (FEET)	DESIGN SPEED (MPH)	GEOMETRIC FEATURES	LINK IMPORTANCE MULTIPLER
90	901	KING USB	89	360	50	LEFT	10
	902	UNIONKWB	94	1193	50	BOTH	10
	903	KING UNB	108	360	50	LEFT	10
	904	UNIONKEB	98	203	50	-	10
94	941	WEBERUSB	78	587	60	BOTH	10
	942	UNIONWWB	-	-	-	LEFT	10
	943	WEBERUNB	-	-	-	LEFT	10
	944	UNIONWEB	90	1193	50	BOTH	10
96	961	BLMNTUSB	-	-	-	-	10
	-962	UNIONBWB					
	962	UNIONBWB	98	304	60	LEFT	10
	963	BLMNTUNB	-	-	-	RIGHT	10
	964	UNIONBEB	-	-	-	-	10
98	981	PARK USB	-	-	-	-	10
	982	UNIONPWB	90	203	50	BOTH	10
	983	PARK UNB	-	-	-	LEFT	10
	-984	UNIONPEB					
	984	UNIONPEB	96	304	50	BOTH	10
108	1081	KING PSB	90	360	50	-	10
	1082	PINE KWB	-	-	-	-	10
	1083	KING PNB	110	288	50	-	10
	1084	PINE KEB	-	-	-	-	10
110	1101	KING KSB	108	288	50	-	10
	1102	PED EW	-	-	-	-	10
	1103	KING KNB	-	-	-	-	10
56	561	KING CSB	-	-	-	-	10
	563	KING CNB	58	247	50	-	10
	564	CNTRLKEB	-	-	-	-	10

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
50	WEBERMSB	68	888	52	0	-	-	-	-	-
	MRSHLWWB	32	64	60	0	-	-	-	-	-
	WEBERMNB	16	984	12	1	684	683	682	-	-
	MRSHLWEB	28	116	32	0	-	-	-	-	-
54	ALBRTBSB	0	0	682	0	-	-	-	-	-
	BRIGPAWB	0	632	176	1	-583	582	581	-	-
	ALBRTBNB	28	456	0	0	-	-	-	-	-
58	KING BSB	0	644	96	2	-	561	564	-	-
	BRIGPKWB	188	596	124	1	603	602	601	-	-
	KING BNB	104	0	0	2	644	643	-	-	-
	KING BNB	0	648	0	2	644	643	-	-	-
60	PEGINBSB	0	236	92	2	-	-	-	-	-
	BRIGPBWB	176	1012	100	2	-703	702	701	-	-
	REGINBNB	60	200	0	3	664	663	-	-	-
62	CARLNESB	472	636	764	0	543	542	541	-	-
	CARLNENB	160	0	0	0	-864	863	862	-	-
	CARLNENB	0	0	456	0	-864	863	862	-	-
	ERB CEB	0	556	24	2	-	-	-	-	-
64	KING ESB	276	0	0	3	582	581	-	-	-
	KING ESB	0	968	0	3	582	581	-	-	-
	KING ENB	0	676	120	2	824	823	822	-	-
	ERB KEB	136	724	92	3	621	624	623	-	-
66	REGINESB	124	240	0	0	602	601	-	-	-
	REGINENB	0	188	220	0	-	-	-	-	-
	ERB REB	48	788	32	2	-641	644	643	-	-
68	WEBEPLSB	92	756	92	0	502	501	504	-	-
	LINCNWWB	184	72	120	0	-	-	-	-	-
	WEBERLNB	48	769	200	0	-	703	702	-	-
	LINCNWEB	128	75	44	0	-	-	-	-	-
70	WEBERBSB	0	788	232	2	682	681	684	-	-
	BRIGPWWB	52	680	224	10	723	722	-	-	-
	WEBERBNB	200	0	0	1	784	783	-	-	-
	WEBERBNB	0	923	0	1	784	783	-	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
72	BRIGPEWB	0	1044	0	1	743	742	741	-	-
	PED MS	0	50	0	0	-	-	-	-	-
74	MRGRTBSB	0	216	12	2	-	-	-	-	-
	BRIGPMWB	80	844	72	3	-	-	-	-	-
	MRGPTBNB	172	268	0	0	804	803	-	-	-
76	MOOREESB	8	112	0	0	-	-	-	-	-
	MOOREENB	0	140	156	0	-	-	-	-	-
	ERB MEB	16	1220	100	2	661	664	663	-	-
78	WEBERESB	180	0	0	2	702	701	-	-	-
	WEBERESB	0	728	0	2	702	701	-	-	-
	WEBERENB	0	864	48	3	944	943	942	-	-
	ERB WEB	252	700	136	2	761	764	763	-	-
80	MRGRTESB	32	248	0	0	742	741	-	-	-
	MRGPTENB	0	320	184	0	-	-	-	-	-
	ERB MEB	44	788	128	1	-781	784	783	-	-
82	KING HSB	48	688	176	3	-	641	644	-	-
	HERBTKWB	8	76	56	1	-	-	-	-	-
	KING HNB	44	544	28	2	844	883	882	-	-
	HERBTKEB	92	48	64	0	-	-	-	-	-
86	CARLNWSB	56	48	424	1	-	621	624	-	-
	WILLMCWB	8	256	40	1	883	882	881	-	-
	CARLNWNB	24	104	100	0	-	-	-	-	-
	WILLMCEB	360	0	0	0	-	-	-	-	-
	WILLMCEB	0	244	0	0	-	-	-	-	-
88	KING WSB	16	604	80	0	822	821	824	-	-
	WILLMKWB	140	208	20	0	-	-	-	-	-
	KING WNB	68	596	68	0	894	893	892	-	-
	WILLMKEB	84	216	80	0	861	864	863	-	-
89	KING ASB	8	692	24	0	882	881	884	-	-
	ALLENKWB	12	28	52	0	-	-	-	-	-
	KING ANB	16	636	8	0	904	903	902	-	-
	ALLENKEB	4	24	44	1	-	-	-	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

INPUT DATA-TRAFFIC CHARACTERISTICS
****

INT'N NO.	LINK NAME	LINK EXIT VOLUMES (VPH)			PERCNT TRUCKS BUSES	SOURCE LINKS				
		LEFT	THRU	RIGHT		LEFT TURNS	THRU	RIGHT TURNS	4TH LINK	SOURCE (MOVE)
90	KING USB	58	380	60	3	892	891	894	-	-
	UNIONKWB	36	328	72	1	943	942	941	-	-
	KING UNB	36	448	76	3	1084	1083	1082	-	-
	UNIONKEB	12	388	36	1	981	984	983	-	-
94	WEBERUSB	60	492	124	C	-	781	784	-	-
	UNIONWWB	4	256	20	0	-	-	-	-	-
	WEBERUNB	152	572	12	1	-	-	-	-	-
	UNIONWEB	160	272	84	0	901	904	903	-	-
96	BLMNTUSB	8	104	0	0	-	-	-	-	-
	UNIONBWB	500	0	0	1	983	982	981	-	-
	UNIONBWB	0	244	16	1	983	982	981	-	-
	BLMNTUNB	96	32	324	2	-	-	-	-	-
	UNIONBEB	0	192	180	1	-	-	-	-	-
98	PARK USB	20	344	188	1	-	-	-	-	-
	UNIONPWB	68	448	32	1	903	902	901	-	-
	PARK UNB	52	440	120	0	-	-	-	-	-
	UNIONPEB	124	0	0	1	961	964	963	-	-
	UNIONPEB	0	284	32	1	961	964	963	-	-
108	KING PSB	24	732	28	3	902	901	904	-	-
	PINE KWB	124	8	20	0	-	-	-	-	-
	KING PNB	32	800	100	2	-	1103	1102	-	-
	PINE KEB	12	0	24	0	-	-	-	-	-
110	KING KSB	0	536	0	0	1082	1081	1084	-	-
	PED EW	0	50	0	0	-	-	-	-	-
	KING KNB	0	1192	0	0	-	-	-	-	-
56	KING CSB	0	612	32	2	-	-	-	-	-
	KING CNB	28	624	0	3	-	583	582	-	-
	CNTRLKEB	136	0	128	0	-	-	-	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

CYCLE LENGTH CALCULATIONS
****

INT'N NO.	SELECTED CYCLE LENGTHS		CALCULATED CYCLE LENGTHS				
	DESIRABLE CYCLE (SEC)	MINIMUM CYCLE (SEC)	MINIMUM CYCLE (SEC)	WEBSTER 0.9*cap (SEC)	WEBSTER 1.0*cap (SEC)	MIN GREEN 0.9*cap (SEC)	MIN GREEN 1.0*cap (SEC)
50	60	60	37	18	17	37	37
54	60	60	32	20	18	32	32
58	60	60	47	25	22	47	47
60	60	60	37	19	17	37	37
62	100	70	43	84	52	99	70
64	60	60	44	49	36	54	49
66	60	60	35	18	16	35	35
68	60	60	44	23	21	44	44
70	60	60	57	28	24	57	57
72	60	60	31	17	16	31	31
74	60	60	40	18	17	40	40
76	60	60	41	17	16	41	41
78	60	60	56	28	25	56	56
80	60	60	43	16	15	43	43
82	60	60	37	21	18	41	39
86	70	60	49	46	35	64	57
88	60	60	45	26	22	45	45
89	60	60	37	14	13	37	37
90	60	60	39	24	21	39	39
94	60	60	47	21	19	47	47
96	80	70	50	80	51	72	69
98	70	60	55	48	37	64	60
108	60	60	35	18	16	35	35
110	60	60	36	29	27	41	38
56	60	60	42	13	12	42	42

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

NETWORK CYCLE LENGTH = 70 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
50	501	WEBERMSB	0.296	0.482	1.98	0.20	585	-	-
	502	MRSHLWWB	0.107	0.441	1.09	0.16	165	-	-
	503	WEBERMNB	0.288	0.469	1.91	0.11	669	11.0	48.6
	504	MRSHLWEB	0.112	0.461	1.15	0.18	173	-	-
54	541	ALBRTBSB	0.393	0.611	1.16	0.43	371	-	-
	542	BRIGPAWB	0.153	0.630	2.40	0.29	590	5.6	26.0
	543	ALBRTBNB	0.274	0.426	0.78	0.14	248	-	-
58	581	KING BSB	0.254	0.635	2.85	0.23	396	6.8	26.9
	582	BRIGPKWB	0.218	0.636	1.17	0.21	248	3.1	27.6
	-583	KING BNB	0.174	1.740	0.13	0.04	18	0.3	32.4
	583	KING BNB	0.220	0.416	0.95	0.08	514	4.7	38.9
60	601	REGINBSB	0.243	0.587	1.42	0.37	277	-	-
	602	BRIGPRWB	0.283	0.600	2.66	0.22	927	23.9	43.9
	603	REGINBNB	0.214	0.517	2.27	0.16	284	3.9	18.8
62	621	CARLNESB	0.561	0.982	4.79	1.21	1565	19.5	34.5
	-623	CARLNENB	0.115	1.150	0.47	0.14	65	0.9	25.2
	623	CARLNENB	0.208	0.297	0.42	0.03	106	4.7	45.0
	624	ERB CEB	0.166	1.056	4.45	8.12	1076	-	-
64	-641	KING ESB	0.294	1.286	1.35	1.87	335	3.5	6.7
	641	KING ESB	0.333	0.569	0.65	0.21	621	6.3	43.1
	643	KING ENB	0.275	0.837	4.59	1.55	803	9.0	15.8
	644	ERB KEB	0.231	0.808	5.28	0.64	832	11.2	23.6
66	661	REGINESB	0.313	0.562	0.75	0.20	257	3.0	34.1
	663	REGINENB	0.313	0.562	1.15	0.32	297	-	-
	664	ERB REB	0.190	0.578	2.46	0.22	475	4.4	19.5
68	681	WEBERLSB	0.263	0.541	2.31	0.16	685	10.8	46.0
	682	LINCNWWB	0.225	0.606	1.80	0.42	328	-	-
	683	WEBERLNB	0.290	0.597	2.44	0.23	796	5.0	27.6
	684	LINCNWEB	0.214	0.576	1.56	0.35	283	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

NETWORK CYCLE LENGTH = 70 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
70	701	WEBERBSB	0.295	0.666	3.29	0.39	911	6.0	23.0
	702	BRIGPWWB	0.149	0.521	4.03	0.12	614	11.8	32.3
	-703	WEBERBNB	0.125	1.250	0.82	0.48	128	1.4	9.7
	703	WEBERBNB	0.256	0.448	1.48	0.09	266	5.1	41.4
72	722	BRIGPEWS	0.188	0.263	0.16	0.01	84	6.3	48.5
	723	PED NS	0.010	0.100	0.36	0.00	45	-	-
74	741	MRGRTBSB	0.126	0.464	1.25	0.18	196	-	-
	742	BRIGPMWB	0.275	0.470	2.20	0.19	607	-	-
	743	MRGRTBNB	0.055	0.203	1.78	0.02	169	3.9	26.9
76	761	MOOREESB	0.068	0.183	0.46	0.02	84	-	-
	763	MOOREENB	0.181	0.487	1.41	0.21	255	-	-
	764	ERB MEB	0.250	0.500	1.65	0.13	692	16.0	44.3
78	-781	WEBEPESB	0.121	1.210	0.67	0.30	99	1.1	11.3
	781	WEBERESB	0.201	0.391	1.03	0.06	163	3.9	42.7
	783	WEBERENB	0.253	0.656	2.18	0.37	759	11.5	46.4
	784	ERB WEB	0.209	0.610	3.42	0.18	845	12.3	35.3
80	801	MRGRTESB	0.157	0.392	1.00	0.06	134	2.4	27.8
	803	MRGRTENB	0.147	0.367	2.02	0.10	384	-	-
	804	ERB MEB	0.178	0.389	1.13	0.06	536	13.1	35.3
82	821	KING HSB	0.333	0.583	1.15	0.21	208	4.6	35.3
	822	HERBTKWB	0.109	0.363	0.77	0.09	126	-	-
	823	KING HNB	0.213	0.373	0.80	0.06	135	3.6	38.1
	824	HERBTNEB	0.175	0.583	1.42	0.37	231	-	-
86	861	CAPLNWSB	0.312	0.840	2.45	1.10	346	8.5	28.6
	862	WILLMCWB	0.180	0.787	1.36	0.77	209	2.8	11.4
	863	CARLNWNB	0.147	0.396	1.10	0.12	199	-	-
	-864	WILLMCEB	0.266	1.095	1.77	1.34	351	-	-
	864	WILLMCEB	0.187	0.374	0.65	0.10	149	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

NETWORK CYCLE LENGTH = 70 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
88	881	KING WSB	0.233	0.627	1.96	0.26	277	5.4	29.2
	882	WILLMKWB	0.339	0.678	1.58	0.64	361	-	-
	883	KING WNB	0.244	0.657	3.87	0.32	668	7.7	22.8
	884	WILLMKEB	0.283	0.566	0.92	0.20	295	1.9	20.5
89	891	KING ASB	0.239	0.380	1.70	0.06	542	5.2	33.1
	892	ALLENKWB	0.067	0.276	0.61	0.05	92	-	-
	893	KING ANB	0.219	0.348	1.37	0.05	503	6.2	38.4
	894	ALLENKEB	0.051	0.210	0.46	0.03	69	-	-
90	901	KING USB	0.241	0.649	2.67	0.31	605	8.1	31.5
	902	ONIONKWB	0.262	0.524	1.03	0.08	214	11.5	45.1
	903	KING UNB	0.193	0.520	2.10	0.14	492	6.3	32.1
	904	UNIONKEB	0.325	0.650	1.23	0.35	277	3.4	26.4
94	941	WEBERUSB	0.185	0.498	1.56	0.13	479	8.4	47.5
	942	UNIONWWB	0.158	0.325	0.78	0.07	173	-	-
	943	WEBERUNB	0.205	0.552	3.24	0.31	588	-	-
	944	UNIONWEB	0.275	0.566	0.93	0.13	295	13.4	45.9
96	961	BLMMTUSB	0.067	0.223	0.54	0.03	88	-	-
	-962	UNIONBWB	0.306	1.190	2.81	3.64	694	7.0	6.6
	962	UNIONBNB	0.419	0.267	0.12	0.03	39	1.7	45.8
	963	BLWNTUNB	0.290	0.967	3.22	8.12	1085	-	-
	964	UNIONBEB	0.228	0.840	2.53	1.98	498	-	-
98	981	PARK USB	0.337	0.813	2.81	1.06	615	-	-
	982	UNIONPWB	0.294	0.935	1.58	1.76	458	5.6	20.0
	983	PARK UNB	0.365	0.881	3.03	2.94	778	-	-
	-984	UNIONPEB	0.032	0.820	0.19	0.01	23	0.3	33.3
	984	UNIONPEB	0.180	0.406	0.54	0.08	135	2.5	37.8
108	1081	KING PSB	0.272	0.476	1.68	0.11	710	7.4	37.9
	1082	PINE KWB	0.177	0.563	1.25	0.33	207	-	-
	1083	KING PNB	0.327	0.572	0.89	0.19	187	6.5	41.5
	1084	PINE KEB	0.034	0.108	0.21	0.01	35	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

NETWORK CYCLE LENGTH = 70 SECONDS

LINK PERFORMANCE
****

INT'N NO.	LINK NO.	LINK NAME	V/S RATIO	DEG. OF SAT.	DELAY (TCU-HRS/HR) UNIFRM	DELAY (TCU-HRS/HR) RANDM	TCU STOPS PER HOUR	TRAVEL TIME (TCU-HRS/HR)	AVG SPEED (MPH)
110	1101	KING KSB	0.175	0.261	0.66	0.02	188	3.8	40.9
	1102	PED EW	0.010	0.100	0.36	0.00	45	-	-
	1103	KING KNB	0.389	0.579	1.84	0.36	640	-	-
56	561	KING CSB	0.184	0.293	0.98	0.05	302	-	-
	563	KING CNB	0.187	0.297	0.42	0.03	129	3.7	43.7
	564	CNTRLKEB	0.072	0.296	1.42	0.06	213	-	-

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

****
* *
* CALCULATED *
* SIGNAL TIMINGS *
* *
* CY = 70 SEC *
****

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET NO. SEC(PERCNT)	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
50	70	47(67)	1	503	WEBERMSE	43(60)	5(7)
				503	WEBERMNE		
			2	502	MRSHLWWE	17(24)	5(7)
				504	MRSHLWEB		
54	70	44(62)	1	542	BRIGPAWB	17(24)	4(6)
			2	541	ALBRTBSE	45(64)	4(6)
				543	ALBRTBNE		
58	70	65(92)	1	-583	KING BNE	7(10)	2(3)
				581	KING BSE	28(40)	4(6)
				583	KING BNE		
			2	582	BRIGPKWE	24(34)	5(7)
60	70	35(50)	1	602	BRIGPRWE	33(47)	4(6)
			2	601	REGINBSB	29(41)	4(6)
				603	REGINBNB		
62	70	40(57)	1	624	ERB CEB	11(16)	6(9)
			2	-623	CARLNENE	7(10)	2(3)
				621	CARLNESE	40(58)	4(6)
				623	CARLNENB		
64	70	21(30)	1	-641	KING ESE	16(23)	2(3)
				641	KING ESE	23(34)	4(6)
				643	KING ENB		
			2	644	ERB KEE	20(29)	5(7)

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

****
* *
* CALCULATED *
* SIGNAL TIMINGS *
* *
* CY = 70 SEC *
****

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET NO. SEC(PERCNT)	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
66	70	57(81)	1	664	EPB REB	23(33)	4(6)
			2	661	REGINESB	39(57)	4(6)
				663	REGINENB		
68	70	12(17)	1	681	WEBERLSE	34(49)	5(7)
				683	WEBERLNB		
			2	682	LINCNWWE	26(37)	5(7)
				684	LINCNWEB		
70	70	5(7)	1	-703	WEBERBNB	7(10)	2(3)
				701	WEBERBSB	31(44)	5(7)
				703	WEBERBNB		
			2	702	BRIGPWWE	20(29)	5(7)
72	70	33(47)	1	722	BRIGPEWE	50(71)	4(6)
			2	723	PED NS	7(10)	9(13)
74	70	16(22)	1	742	BRIGPMWB	41(59)	5(7)
			2	741	MRGRTBSB	19(27)	5(7)
				743	MRGRTBNB		
76	70	18(25)	1	764	ERB MEB	35(50)	4(6)
			2	761	MOOREESB	26(37)	5(7)
				763	MOOREENB		
78	70	6(8)	1	-781	WEBERESB	7(10)	2(3)
				781	WEBERESB	27(39)	5(7)
				783	WEBERENB		
			2	784	ERB WEB	24(34)	5(7)

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

****
* CALCULATED *
* SIGNAL TIMINGS *
* CY = 70 SEC *
****

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET NO. SEC(PERCNT)	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
80	70	19(27)	1	804	ERB MEB	32(46)	5(7)
			2	801	MRGRTESB	28(40)	5(7)
				803	MRGRTENB		
82	70	22(31)	1	821	KING HSB	40(57)	4(6)
				823	KING HNE		
			2	822	HERBTKWB	21(30)	5(7)
				824	HERBTKEB		
86	70	7(10)	1	861	CARLNWSE	26(37)	4(6)
				863	CARLNWNB		
			2	-864	WILLMCEB	17(24)	2(3)
				862	WILLMCWB	16(23)	5(7)
				864	WILLMCEB		
88	70	29(41)	1	881	KING WSB	26(37)	4(6)
				883	KING WNB		
			2	882	WILLMKWB	35(50)	5(7)
				884	WILLMKEB		
89	70	57(81)	1	891	KING ASB	44(63)	4(6)
				893	KING ANB		
			2	892	ALLENKWB	17(24)	5(7)
				894	ALLENKEB		
90	70	26(37)	1	901	KING USB	26(37)	4(6)
				903	KING UNB		
			2	902	UNICNKWE	35(50)	5(7)
				904	UNIONKEB		

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

****
* CALCULATED *
* SIGNAL TIMINGS *
* CY = 70 SEC *
****

INT'N NO.	CYCLE LENGTH (SEC)	OFFSET NO. SEC(PERCNT)	PHASE NO.	LINK NO.	LINK NAME	GREEN TIME SEC(PERCNT)	CLEARANCE INTERVAL SEC(PERCNT)
94	70	44(62)	1	941	WEBERUSB	26(37)	4(7)
				943	WEBERUNB		
			2	942	UNIONWWB	34(49)	5(7)
				944	UNIONWEB		
96	70	9(12)	1	-962	UNIONBWB	18(26)	2(3)
				962	UNIONBWB	19(27)	5(7)
				964	UNIONBEB		
			2	961	BLMNTUSB	21(30)	5(7)
				963	BLMNTUNB		
98	70	57(81)	1	-984	UNIONPEB	7(10)	2(3)
				982	UNIONPWB	22(31)	5(7)
				984	UNIONPEB		
			2	981	PARK USB	29(40)	5(7)
				983	PARK UNB		
108	70	55(78)	1	1081	KING PSB	40(57)	4(6)
				1083	KING PNB		
			2	1082	PINE KWB	22(31)	4(6)
				1084	PINE KEB		
110	70	44(62)	1	1101	KING KSB	47(67)	4(6)
				1103	KING KNB		
			2	1102	PED FW	7(10)	12(17)
56	70	0(0)	1	561	KING CSB	44(63)	5(7)
				563	KING CNB		
			2	564	CNTRLKEB	17(24)	4(6)

WATERLOO CBD INITIAL OPTIMIZATION - P.M. PEAK

TOTAL SYSTEM PERFORMANCE VALUES
****

TRIAL CYCLE LENGTH (SEC)	NO. OF KICKED OUT SIGNALS	TOTAL DELAY (TCU-HRS/HR)		TCU STOPS PER HOUR	PERF. INDEX	TOTAL INTRNL TRAVEL TIME (TCU-HRS/HR)	AVG. SYSTEM SPEED (MPH)
		UNIFORM	RANDOM				
60	2	147.1	64.4	38512	254.2	377.9	34.4
70	0	151.3	50.3	35913	241.4	368.1	35.4
80	0	171.9	44.7	35815	256.4	379.8	34.3
90	0	193.4	37.3	34783	269.3	393.8	33.1

THE OPTIMUM CYCLE IS 70 SECONDS

APPENDIX E

ERRORS

APPENDIX E - ERRORS

The SSTOP program, while reading the input data, performs various checks to ensure that the proper card sequence is followed, the correct number of each card type is provided, the network to be optimized does not exceed program capabilities and that network integrity is maintained. Violation of any of these checks results in the printing of a message and immediate program termination. These messages, and possible remedial actions, are discussed in Section F.1. In most cases the message is felt to be self-explanatory but appropriate diagnostics are included. They are arranged with respect to the error number.

In addition, all alpha-numeric fields, except for the user-identifiable title on card 1 and the link names (card 3, columns 11-20) are always checked to ensure only legitimate entries are made. It is also possible by entering a 'YES' or 'Y' for Data Check? on card 2, columns 51-55 to check all integer fields in cards 3 and 4 for legitimate entries. This type of check is always done for card 2 and for card 5, if it is included. This option is discussed in more detail in Section E.2.

Section E.3 briefly discusses the non-fatal SSTOP messages which may be printed during optimization.

E.1 FATAL ERROR MESSAGES

E.1.1 Error 1

> The first card in the data deck is not card type 1 as it should be. Check card sequence in the data deck and resubmit.

Diagnostic - Card type 1 is misplaced in data deck or not included.

E.1.2 Error 2

> The second card in the data deck is not card type 2 as it should be. Check card sequence in the data deck and resubmit.

Diagnostic - Card type 2 is misplaced in the data deck or not included.

E.1.3 Error 3

The number of links in the network (XXX) is greater than the available link storage in the program.

Diagnostic - The number of card type 3's read by SSTOP (XXX) or the number of links specified on card type 2, columns 26-30 exceeds the present program storage capabilities the size of which, at present, is YYY. Either the network may be subdivided into two or more smaller networks, or delete sufficient links from the network, or the program storage must be increased by changing the value of YYY to some greater value. If the program link dimensions are to be increased, it would be advisable to check the program intersection dimension to ensure that it to provides sufficient storage space.

E.1.4 Error 4

The number of links (XXX) for which information is provided is less than the number of links specified on card type 2 columns 26-30 (YYY).

Diagnostic - Improper counting of number of links in network (each card 3 represents one link), missing data or a mispunch on card type 2, columns 26-30.

E.1.5 Error 5

The number of card types 3 (XXX) and hence the number of links exceeds the number of links specified on card type 2, columns 26-30 (YYY).

Diagnostic - Improper counting of number of links in network (each card 3 represents one links), too many data cards or a mispunch on card type 2, columns 26-30.

E.1.6 Error 6

The number of intersections in the network (XXX) is greater than the available storage in the program.

Diagnostic - The number of intersections, XXX, specified on card type 2, columns 31-35 exceeds the available program storage capabilities, YYY. The network may be subdivided into a number of subnetworks, a sufficient number of intersections dropped from the network, or the program storage limits may be increased by increasing YYY.

If the program intersection dimension is to be increased, it would be advisable to check the program link dimension to ensure that it provides sufficient storage space.

E.1.7 Error 7

> The number of green time periods in the network (XXX) identified from card type 3's exceeds available program storage.

Diagnostic - This error message should not, at present, ever be called. It is included in anticipation of possible future expansion to multi-phase links.

E.1.8 Error 8

> The program expected card XXX in the data deck to be a card type 3. Instead a card type Y was read with link number XYZ on it. Check the card sequence at this point.

Diagnostic - The XXX card in the data deck, starting count from the first card in the deck, is supposed to be card 3. Either the cards have been improperly placed in the data deck or a mispunch occured. a negative or positive link card 3 is followed by the neutral link card 3. See Sections 3.3 and 3.4.

E.1.9 Error 9

> The program expected card no. XXX in the data deck to be card type 4. Instead a card type Y was read with link number XYZ on it. Check the card sequence at this point.

Diagnostic - The XXX card in the data deck, starting count from the first card in the deck, was expected to be a card 4. Either the cards are improperly placed in the data deck or a mispunch occurred. A card type 4 immediately follows a neutral card type 3. See Sections 3.3 and 3.4.

E.1.10 Error 10

> The link number XXX on card number YYY of the data deck (a card type 4) is not the same as the link number on the preceding card type 3.

Diagnostic - Mixup of cards 3 and 4 when structuring deck or mispunched link number on either card 3 or 4. Only neutral link numbers appear on card 4. Card 4's follow only neutral link card 3's in the data deck.

E 1.11 Error 11

> The card following optional card 5 should be card 99999. Instead a card XXX was encountered.

Diagnostic - Improper placement of card 5 in data deck or failure to terminate data with card 99999 (see Section 3.9).

E.1.12 Error 12

> The number of intersections identified from the link numbers exceeds the number of intersections specified on card type 2 columns 31-35. This error occured as card no. XXX with link number YYY on it was being read.

Diagnostic - Improper network representation on data deck structuring. All links having outflow controlled by the same intersection must have a link number composed of that intersection number followed by a one digit direction code. Also, the data cards for links having outflow controlled by the same intersection must occur as a group within the data deck (see Section 3.3 and 3.4)

Alternatively, the number of intersections within the network may have been counted improperly or there may be a mispunch on card 2, columns 31-35.

E.1.13 Error 13

> The number of intersections identified from the link numbers (XXX) is less than the number of intersections specified on card type 2 columns 31-35 (YYY).

Diagnostic - most probably a mispunch on card type 2 columns 31-35 or improper counting of number of intersections in network. Also check to ensure two neighbouring intersections do not have the same number.

E.1.14 Error 14

> Upstream intersection no. XXX does not have any links associated with it. Either one or more links have been omitted from the network or link no. YYY is an external link and should have no upstream intersection.

Diagnostic - link number YYY has an upstream intersection number XXX specified for it on card 4 columns 11-15. However this upstream intersection number is not used as the root for any of the links in the network. A number of possible reasons exist for this error. The most likely are a mispunch in columns 11-15 of card 4 for link YYY, or link YYY is external and should not have an upstream intersection. Another possibility is that several links were not included in the network schematic diagram and hence were not coded.

E.1.15 Error 15

> Link XXX has an upstream intersection specificied but has no source links. Either its parallel link is misplaced in the data deck or does not exist, or the source links must be specified.

Diagnostic - this error can only occur for links having a direction code greater than four as for all other links the program would construct source links. Either this link is an external, and should therefore have no upstream intersection, or the parallel link has been misplaced in the data deck, has not been included, or has an upstream intersection number different from that of link XXX (check for mispunches). The parallel link with direction code less than four should appear before the parallel link with direction code greater than four in the data deck. Alternatively, the source links for any internal link with direction code greater than four must be specified.

E.1.16 Error 16

> The program expected card XXX in the data deck to be a card type 6 or card 88888. Instead a card type YYY was found.

Diagnostic - improperly punched card or cards out of sequence as the XXX card was being read.

E.1.17 Error 17

> The program expected XXX card types 6. However only YYY were read.

Diagnostic - most probably resulting from an insufficient number of card types 6 being supplied.

E.1.18 Error 18

> No match was found for intersection number XXX on card number YYY of the card types 6 with an intersection identified from card types 3 and 4. Check intersection number on this card.

Diagnostic - SSTOP, on processing card types 3 and 4 strips the link direction code from the link numbers and hence identifies all intersections in the network. For the intersection number XXX specified on the YYYth card type 6 however, no match was found. Most probably then this intersection number has been improperly entered.

E.1.19 Error 19

> The link cards for intersection XXX are improperly sequenced. Intersection XXX was identified a second time as card no. YYY was read.

Diagnostic - all card types 3 and 4 for all links having the same downstream intersection, that is, having the same link number except for the direction code (the last digit of the link number) must appear as a group in the input data deck. For intersection XXX a second set of data cards was found as the YYYth card was being read.

E.1.20 Error 20

> Intersection XXX has more than six green periods. Each advanced or delayed green phase is equivalent to two green periods.

Diagnostic - SSTOP can evaluate links having only six or fewer green intervals. However more than six have been identified for intersection XXX. Keeping in mind that each split phase has two green intervals check coding for this intersection. Ensure that all phase numbers on card types 3 for this intersection are equal to six minus the number of split phases for this intersection.

E.1.21 Error due to Oversaturation

```
************************************
*                                  *
*       PROGRAM TERMINATED         *
* INTERSECTION XXXX OVERSATURATED  *
*   SEE USERS GUIDE, APPENDIX E    *
*                                  *
************************************
```

CRITICAL SPLITS
FOR EACH GREEN
PERIOD ARE

XXX
YYY
ZZZ

Check input data for this intersection and ensure all entries are correct.

Remember

1. To apply tcu conversions to input volumes allowing for any geometric features.

2. Any priority green requires a separate V/S calculation.

3. The volume for a priority green after discounting for vehicles cleared in amber is set to at least 15.

4. A minimum V/S ratio of 0.01 is set

Diagnostic - the sum of the critical V/S ratios for each green period exceeds 1.0. The signal is incapable of meeting demand at any cycle length, and is therefore always oversaturated. SSTOP does not account for oversaturated signals and therefore terminates.

Check the volumes and saturation flows for all links pertaining to this signal and ensure they are properly entered. When calculating V/S ratios manually remember to take into account the above mentioned operations. If all entries are correct, the signal must be removed from the network to be optimized, the number of phases decreased, the volume on the critical approaches reduced or the saturation flow on these same approaches increased.

E.2 ILLEGAL DATA CHECK

SSTOP, in reading the input data, checks a number of the data fields to ensure that only permissible entries are made. With of entry of 'YES' or 'Y' in columns 51-55 of card type 2, this check is performed for all fields.

The columns on which checks are <u>always</u> performed, and the entries allowed in each are outlined below.

a) Card type 2

Columns	Permissible entries
6-45	0-9 or blanks
46-50	blanks in 46-49, zero in 50 or blanks in 46-49, 'Y' in 50 or blanks in 46-49, 'YES' in 48-50 or blanks in 46-50
51-55	similar to above
56-60	similar to above

b) Card type 3

Columns	Permissible entries
6-10	Link number immediately preceded by plus or minus sign if required. Blank spaces between these signs and the digits are not allowed.

c) Card type 4

Columns	Permissible entries
26-30	blanks in 26-30 or blanks in 26-29, zero in 30 or blanks in 26-29, 'L' in 30 or blanks in 26-29, 'R' in 30 or blanks in 26-29, 'B' in 30 or blanks in 26-29, 'T' in 30 or blanks in 26-29, 'ONE' in 28-30 or blank in 26, 'LEFT' in 27-30 or blank in 26, 'BOTH' in 27-30 or 'RIGHT' in 26-30
76-80	If columns 71-75 blanks or 71-74

blanks and 75 is zero, then
blanks in 76-80
or blanks in 76-79, zero in 80.
If any other entry in 71-75 then
blanks in 76-79, 'L' in 80
or blanks in 76-79, 'T' in 80
or blanks in 76-79, 'R' in 80
or blanks in 76, 'LEFT' in 77-80
or blanks in 76, 'THRU' in 77-80
or 'RIGHT' in 76-80

d) Card type 5 if included

Columns	Permissible entry
6-20, 26-30	one decimal point, blanks or 0-9
21-25	blanks or 0-9

If the entry in columns 51-55 of card type 2 is 'YES' or 'Y', SSTOP also checks card type 3, columns 21-40, card type 4 columns 6-25, and card type 4, columns 31-75 to ensure that only blanks or digits (0-9) are contained in these fields. If the Data Check? option is not used, a system generated error will result should illegal data be found.

Should any illegal data be found by SSTOP a message is printed listing the card type and card number sequence in the data deck as well as providing a copy of the card with any illegal entries underlined (see Figure E.1). For card types 2, 3, and 5 the copy of the card begins from columns 6. Since card 4 data exceeds 72 columns the link number is printed separately. The entries from columns 10-80 are then printed on the following line.

SSTOP will continue processing data cards until the end-of-data indicator (card 99999) is found or until a fatal error is encountered. If all data has been checked and no illegal data errors have been found SSTOP continues execution; otherwise the program terminates at this point.

E.3 NON-FATAL MESSAGES

Several further checks are performed by SSTOP during optimization of the network. If SSTOP finds that there are less than two signals remining to be optimized following KIKOUT, the program terminates any further processing of this cycle and moves to the following one. A simple message is printed for the non-optimized cycle, with no performance indicators or timings being calculated for that cycle length.

Checks are also made on the minimum and maximum system trial cycle lengths and on the cycle length increment. If any constraints are violated SSTOP prints a self-explanatory message, adjusts the parameters internally, as required, and proceeds with execution employing the adjusted data.

```
CARD TYPE 2
                        a                          b
 80   10   100   12A    96   28   4   4   Y    Y
                 -----                      ----


CARD TYPE 3 ERROR
CARD NO. 15 IN CARD DECK
   c
 -  102EXAMPLLINK    1   2400   14
-------


CARD TYPE 4 ERROR
CARD NO. 38 IN DATA DECK FOR LINK NO. 1234
                      d                                                  e
 10   1004   28  LFFT   80   194   122   5       101  104  103  RIGHT
                -------                                          -----


CARD TYPE 5 ERROR
             f
 1.85  1..2  2.5   85
      ------
```

a) A is illegal entry. Only numerics printed
b) Y is in incorrect column. It should be right-justified
c) Minus sign should immediately precede link number. Spaces not allowed
d) Entry mispunched. Instead of LEFT, LFFT is entered
e) Fourth source link turning movement read, but no fourth source link entered
f) Two decimal points inadvertently punched

FIGURE E.1 Illegal Data Entries

APPENDIX F

COMPUTER SYSTEMS SET-UPS

JCL SET-UP FOR IBM SYSTEMS (SAMPLE)

```
// Job Card

// STEP1   EXEC PGM=SSTOP2, REGION=200K
// STEPLIB  DD DSN=TCSR.AU4123, DISP=SHR
// FT06F001 DD SYSOUT=A
// FT25F001 DD UNIT=DISK, SPACE=(CYL,(1,1))
// FT05F001 DD *


   Data


/*
//
```

CONTROL CARD SET-UP FOR CDC SYSTEMS

```
Jobcard, JC3
USER (#,PW)
CHARGE (  )
RESTAPE (NT=1)
LABEL (TAPE,D=PE,PO=R,LB=KU,VSN=9UXXXX)
SKIPF,TAPE.
COPYBF,TAPE,BIN.
COPYBF,TAPE,DATA.
REWIND,DATA.
BIN,DATA.
E.O.I.
```

(Note: Use tape 9U1506 as an example.
Tape 9U1506 has 4 files: 1 - source program
2 - binary program
3 - St. Catharines network data
4 - output

Major SSTOP Subroutines within MAIN Program

CHECK
INPT
OUTPT
SPRITS
KIKOUT
FLOPAT
IDEALO
IMPORT
SUBNET
NETWRK
SIGOS
FTABLE
FINAL